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Pleistocene of Northern Kentucky and other papers

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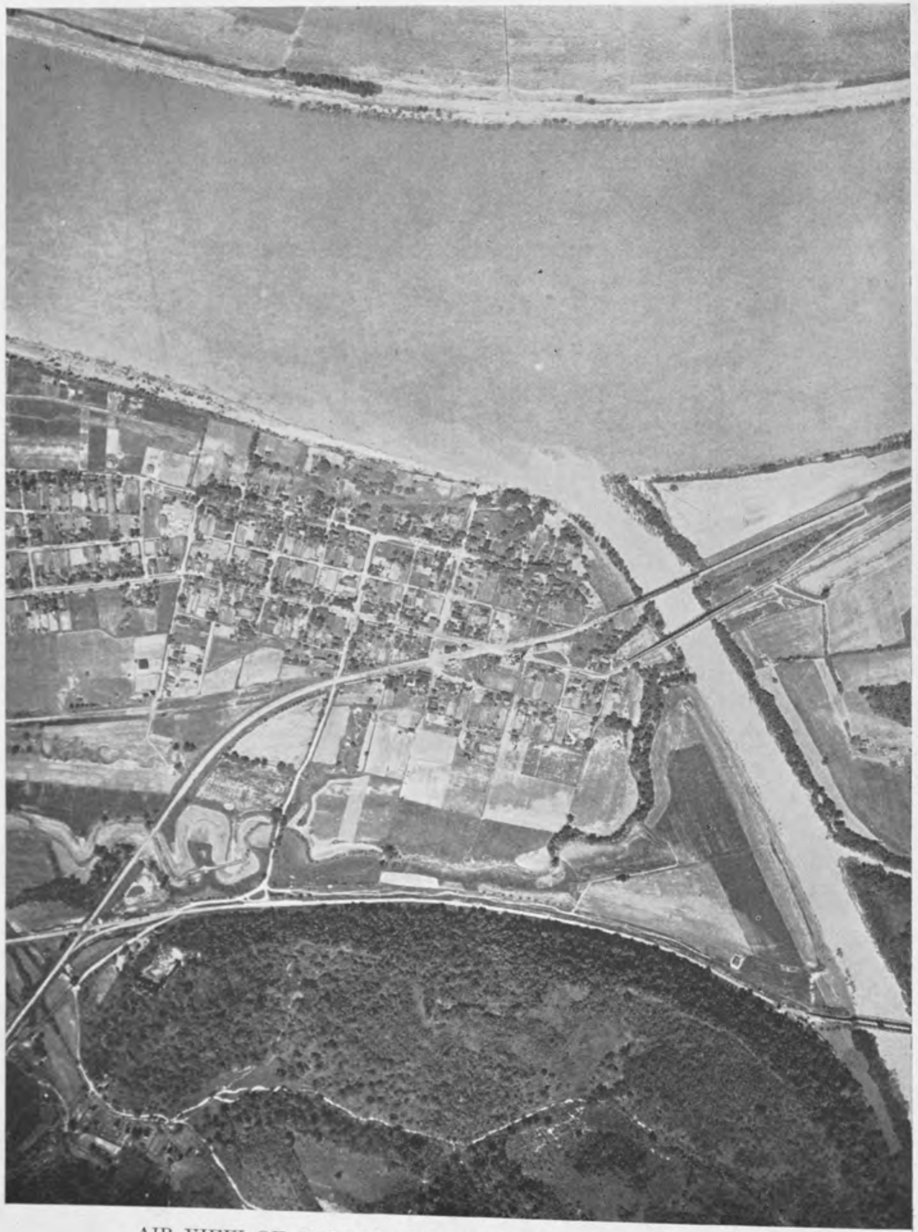

AIR VIEW OF TOPOGRAPHY AT MOUTH OF SALT RIVER
Glacial and Post Glacial Trenching of the Ohio Valley is here shown at West Point, Kentucky.

THE PLEISTOCENE *of* NORTHERN KENTUCKY

A Regional Reconnaissance Study of the Physical Effects of Glaciation within the Commonwealth

By FRANK LEVERETT
Assistant Geologist

Preface by T. C. CHAMBERLIN

Presented with Four Separate Geological Papers

By

STEPHEN SARGENT VISHER
ARLE H. SUTTON
JAMES K. ROBERTS *and*
ARMIN KOHL LOBECK

Illustrated with Sixteen Photographs, Maps, and Diagrams

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Preface

More than forty years ago the writer of this prefatory note, at the suggestion of J. D. Dana, published a paper in the American Journal of Science[1] on the correlation of eastern and western terminal moraines as then known. An eastern moraine had been traced across New Jersey by Cook and Smock, and thence eastward to the Cape Cod region by Upham and others. This lay on or near the border of the glacial drift as then known. A much more extensive terminal moraine on the border of what was then called the drift of Second Glacial Epoch had been traced by the writer and others from the upper Mississippi states as far east as the western border of Pennsylvania. In the Mississippi Valley it lay far back from the drift limit, but it approached the border of the older drift in eastern Ohio, and became almost coincident with it as the two passed into Pennsylvania. It had been noted that while the later drift (now called Wisconsin) bore a pronounced terminal moraine at its border, the older drift of the interior, where the two were well separated, usually had an attenuated border. It had been further noted that scattered erratics could often be found at considerable distances beyond the border of continuous drift. Where the moraine of the later epoch passes from Ohio into Pennsylvania, scattered erratics were seen outside it for a few miles and were thought by the writer to belong to the older drift, and the question whether they belonged to the older or the younger drift was raised in the article cited, but was there simply put as an open question, since the gap between Ohio and New Jersey was then being examined by Lewis and Wright of the Pennsylvania survey. In preliminary notices they had designated the thin scattered drift they found outside the New Jersey moraine, as they traced it westward, "the glacial fringe" and interpreted it as a feature of the later drift. Thus more than forty years ago the nature and the relations of this border of thin drift and scattered erratics was definitely raised and its

[1] "The Bearing of Certain Recent Determinations on the Correlation of Eastern and Western Moraines," by T. C. Chamberlin, Am. Jour. Sci., Vol. XXIV, August, 1882, pp. 93-97.

interpretations became a declared issue. On it at the time hung largely the question whether the New Jersey moraine traced by Cook and Smock was the eastern equivalent of the "terminal moraine of the Second Glacial Epoch" traced by Chamberlin and others in the interior, or whether the New Jersey moraine was the equivalent of the border of the outer and hence, in some sense at least, older drift of the interior. And this in turn soon became a leading issue in the broader question whether the glacial period was short and simple or prolonged and oscillatory, embracing at least two rather distinct epochs.

Thus it came about that this "fringe" of scattered erratics and thin drift that sometimes accompanied it, more than perhaps any other single feature of the glacial deposits, at that date marked the vital issue between the earlier and later views of the divisibility of the glacial period in America. And it has never ceased to play an important part in the interpretation of the history of the Pleistocene Period by some of the most experienced glacialists.

Later, it was shown by Salisbury and others, working on behalf of the New Jersey Survey, that scattered patches of thin till and other glacial deposits were retained in the form of erosion remnants on suitable uplands at considerable distances south of the terminal moraine traced by Cook and Smock on the border of the later drift, which is now generally identified as belonging to the Wisconsin Epoch. The character of these patchy remnants gave physical evidence in themselves that they were in no sense dependencies of the moraine traced by Cook and Smock, but were much older. The broad erosion valleys which separated these remnants gave even more impressive evidence of a long interval between the formation of this old drift and the formation of the moraine named and the till sheet that lies north of it.[2]

Not much later, Leverett[3] verified the reference of the thin and scattered border drift in western Pennsylvania to the older drift and added both erosional and internal evidence of its great age. More recently Atwood,[4] working on the borders of the

[2] See R. D. Salisbury: Ann Repts. New Jersey Geol. Survey, 1893-1897, and Final Report, Vol. 5, 1902.
[3] Frank Leverett: Monograph XLI, U. S. Geol. Survey, 1902, pp. 228-252.
[4] W. W. Atwood and K. F. Mather: Jour. Geol., Vol. 20, 1912, pp. 386-409.

San Juan Mountains in Colorado, and Alden,[5] working in front of the Rocky Mountains in Montana, independently demonstrated the occurrence of isolated patches of glacial deposits whose topographical relations and internal features bore evidences of great age. It is a far cry from the plains of New Jersey to the San Juans and the Rockies, but the erosional isolations of the observed remnants and the inherent signs of age in the remnants themselves strongly impress one with the view that these much worn and weathered relics of glacial action are all members of the earliest Pleistocene glaciation of the low latitudes.

So, also, at a very early day, observers of the Kansas and Missouri glacial formations called attention to a singularly wide distribution of scattered boulders beyond the border of continuous drift. This has special significance, both because it was independent of those cited above and because the location in the midst of the great interior plains frees it from any assignable influence of coastal agencies or interior mountains.

Many other observations of this phenomenon have been made at various times and at various points on the drift border between the Atlantic and the Rocky Mountains. The questions of correlation and interpretation to which these have given rise, have added force to the desire long cherished by the older students of the problem for a more intensive study of the phenomena all along the glacial front.

And so, in taking up this work in the thorough way indicated in this paper of Mr. Leverett's, the Kentucky Survey has earned the gratitude of all true students of the glacial history of our continent. When completed it should equally have won the appreciation of educators and intelligent citizens generally. The thinking world has come to realize that commercial, as well as intellectual value, is almost certain to spring in one way or another from all advances in knowledge of the agencies that have made our land what it is, whether such values are obvious at first or not. Dr. W. R. Jillson, State Geologist of Kentucky, who personally has already done much in the glacial field of that area, could not have put this work into better hands than those of Mr. Leverett, whose long experience, unceasing industry and cool but persistent enthusiasm give him unsurpassed qualifications for the task.

[5] W. C. Alden: Bull. Geol. Soc'y America, Vol. 23, 1912, pp. 687-708; Vol. 24, 1913, pp. 529-572.

April 7, 1925.
University of Chicago,

The PLEISTOCENE *of* NORTHERN KENTUCKY
AND OTHER PAPERS

PLEISTOCENE OF NORTHERN KENTUCKY

By Frank Leverett,

Introduction.

The present report treats incidentally of the non-glacial deposits, but deals mainly with the glacial and aqueo-glacial deposits of northern Kentucky. These deposits were given some attention by the writer in the 1890's under the auspices of the United States Geological Survey, and the results of the study were presented in a report on the Glacial Formations and Drainage Features of the Erie and Ohio Basins[1] and later in a report on the Pleistocene of Indiana and Michigan.[2] These deposits were the subject of further study in the field season of 1924, under the auspices of the Kentucky Geological Survey. The Director of the Kentucky Geological Survey, and members of his staff, had made surprising finds of glacial or aqueo-glacial erratics in eastern Kentucky in 1923 and the early part of 1924[3] which made evident the need for further study of these features, and the present writer was engaged to carry on these studies. The interpretations here presented are necessarily tentative because of the incompleteness of the investigation. There is need for a wider and more comprehensive study extending into neighboring States, as well as for more detailed study in this field. The main result of the season's work has been the more precise mapping of the limits of the Illinoian drift along the south side of the Ohio River. The method of deposition of erratics of glacial derivation outside the limits of the Illinoian drift remains a problem at present writing. Their age is also still subject to question. Related problems, still unsettled, pertain to the drainage changes in the Ohio Basin, and the role glaciation has played in producing these changes. With these problems are included the features that have been interpreted by some geologists to indicate a relatively recent submergence

[1]Monograph XLI, U. S. Geol. Survey, 1902.
[2]Monograph LIII, U. S. Geol. Survey, 1915.
[3]Big Sandy Valley. By Willard Rouse Jillson, Louisville, 1923, p. 25. Science, Vol. LX, pp. 101-102, 1924. Pan-American Geologist, Vol. XLII, 1924, pp. 125-132.

in the Ohio River Basin. It remains to be determined to what extent these features are dependent, directly or indirectly, upon glaciation, also, if dependent upon glaciation, to what glacial stage they are referable. Much further work is necessary in the district north of the Ohio, and also in West Virginia and Pennsylvania to determine to what height the submergence or flooding extended, and the relation, if any, to the Pleistocene ice-sheets. These States are better supplied with topographic maps, by which altitude relations may be determined, than is Kentucky. Those north of the Ohio also stand in nearer relation to the several drift sheets.

The non-glacial deposits, Irvine Formation, Ohio River Formation, Lafayette gravel, etc., merit a more systematic and comprehensive study than has thus far been given them. The present report presents merely a few notes concerning them. It is evident that some of these deposits are fluvial, but the Ohio River Formation may not fall in that class of deposits. It seems to have been deposited in a time of low altitude, but it was preceded by one much higher, in which there was a development of sink holes, and underground drainage, in certain limestone formations which it covers. Its relation to the polished cherty gravel of fluvial character farther down the Ohio, both in time and in genesis, is undetermined.

The suggestions here made as to former courses of drainage of some of the streams that now enter and follow the lower Ohio are still lacking in decisive data. But the suggestions may serve to stimulate further study that will either corroborate or overthrow them. It is evident that the Ohio is a relatively recent combination of drainage systems. But it is also probable that some of the combinations date from a more recent time than others.

Residuals on Uplands

The oldest surface deposits of northern Kentucky are the residuals left on uplands, from formations that have been broken down and otherwise almost entirely removed. Thus there are found over a large part of the Lexington plain, pebbles of white quartz, such as occur in the Pottsville Conglomerate, which were either let down in the course of the dissolution of this formation, or were brought in by drainage systems which to a large degree

antedate the development of the present deeply incised drainage lines. Other resistant rocks, more or less waterworn, also seem to have been left as residuals. While such stones probably have some relation to ancient systems of drainage there is very little in present topography on which to base a restoration of such systems.

Where the formations were of sandstone or conglomerate there is very little remaining except such resistant pebbles. Geodes, present in certain shales, persist after the shales are removed. Formations with chert beds involved in them, as in some of the limestones of western Kentucky, have lost their calcareous parts, but the chert, and a residuary clay are preserved and in places ferruginous material in sufficient amount to be classed as iron ore. In places the limestone has been completely dissolved to depths of 50 feet or more, while the chert beds still remain sufficiently intact to show the bedding planes. These cherts show no water wear or evidence of stream transportation, and are thus strikingly different from the waterworn and polished cherts found in the old drainage lines in this region. Some of the best exposures of these residuary chert beds are found on the borders of the Cumberland River near Kuttawa, in railway cuts which expose them to depths of fully 50 feet.[4]

Tertiary Deposits

Under this topic are discussed deposits of transported material which are largely unconsolidated sand and gravel of different composition than the underlying consolidated rock formation. They are present to some extent on uplands but also occupy broad shallow trough-like valleys, which antedated the cutting of the deep valleys of the region. Deposits of this sort near the mouth of the Ohio, in southern Illinois, were classed as Tertiary by Worthen in 1866[5], and those in southern Indiana by Cox in 1872.[6] Those of southern Illinois were shown to rest on clay and sand of Eocene age, thus making it certain that they

[4]Briet discussions of the residuary deposits of central Kentucky, by Prof. N. S. Shaler, appear in Rept. of Progress, Geol. Survey of Kentucky, 1877, and in his paper on the "Origin and Nature of Soils" in Twelfth Ann. Rept. U. S. Geol. Survey, 1891, pp. 302-303. Prof. A. M. Miller has discussed the residuals of the same region in Bull. Geol. Soc. America, vol. 20. 1909, pp. 621-624.

[5]A. H. Worthen, Geol of Illinois, Vol. 1, 1866, pp. 44-46.

[6]E. T. Cox, Third Ann. Rept. Ind. Geol. Survey, 1972, p. 138.

fall in the middle or later Tertiary. As shown by Call,[7] there was a complicated series of uplifts and subsidences in the region near the mouth of the Ohio between the deposition of the Eocene sand and clay and the gravel deposits of that region which cover middle Tertiary time, thus throwing the gravel deposition into late Tertiary time. This interpretation seems to have been confirmed by later students. The name Lafayette gravel has been generally adopted for this deposit.

The upper limit of the gravel deposits along the lower Ohio is found to be but little above 700 feet at the most eastern exposures near Brandenburg, Ky., and is slightly below 600 feet near the mouth of the Ohio. But there are higher deposits of sandy character on the Knobstone escarpment in southern Indiana, with an upper limit about 1,000 feet, to which Ashley gave the name Ohio River Formation,[8] and which because of their presence on this prominent escarpment he was inclined to refer to an earlier time than the gravel deposition on the lower land to the west. He, however, in the absence of fossils or other age criteria, was unable to assign the formation a definite place in the geological column.

Deposits of sandy character on the Kentucky at similar height to these on the Knobstone escarpment have been described by Campbell under the name "Irvine Formation."[9] He classified them tentatively as Neocene, but they are probably as recent as the late Tertiary deposits of the lower Ohio, and will be discussed in connection with them. Deposits on the uplands bordering the lower course of the Licking River are also treated in the same connection. These all seem to antedate the well defined fluvial plains on valleys which were combined to form the Ohio drainage system, as discussed below. The Irvine Formation will be treated first, not because it is thought to be the oldest, but in order to treat the deposits along the Ohio consecutively.

Irvine Formation

The present writer has not had opportunity to examine the deposits described by Campbell in the Richmond quadrangle,

[7] R. Ellsworth Call, Ark. Geol. Survey, Vol. II, Crowley's Ridge, 1889, pp. 125-131.

[8] George H. Ashley, 27th Ann. Rept. Ind. Geol. Survey, 1902, p. 68-70.

[9] Marius R. Campbell, Geol. Atlas of United States, Folio 46, Richmond, Kentucky, 1898, p. 3.

and has seen but one place farther down the Kentucky valley that seems to carry this formation, namely at Alton, Kentucky. Descriptions by Campbell, and also by Miller are, therefore presented.

"*Irvine Formation.* The Irvine formation consists of unconsolidated sand, gravel, and clay, which originally covered the intermediate valley of the Kentucky River near the eastern edge of this quadrangle, but which are now found capping the river hills—the few remnants of what was once an extensive and continuous surface. It is named from the town of Irvine, which is located on the Kentucky River a few miles above the eastern margin of this quadrangle. No fossils have been found in these sands by which to ascertain their position in the geologic time scale, so that we are forced to fix their age by their relation to the topography of the region. Unfortunately the dates of the principal topographic features have not been accurately determined, and that of the Irvine formation can be stated only provisionally.

"This formation has been considered by some geologists to be of Glacial age, but its close connection with the Lexington peneplain certainly indicates that it is much older than the Pleistocene period. Since the sand occurs on the intermediate valley of the Kentucky River, and is disssected by erosion which produced the gorge of that stream, it must have been deposited in the period that intervened between the cutting of the intermediate valley and the cutting of the gorge. The geologic period in which the intermediate valley was eroded has not been determined with certainty, but since it is cut only a slight distance below the surface of the Lexington peneplain, and to only a moderate breadth, it must have been formed soon after the peneplain was raised above base-level. The age of this peneplain has been provisionally accepted as Eocene, and that of the intermediate valley as Neocene; hence the deposits lying upon the floor of the intermediate valley must have been laid down after the valley was cut, or presumably in the closing stages of the Neocene period. They are therefore assigned to the Neocene, but the classification is held subject to revision in case of the discovery of more definite information."

The latest discussion of the Irvine Formation by Prof. A. M. Miller appears to be in his official report on Franklin County, Kentucky, published in 1914, where it is briefly treated as follows[10]:

"Both the very winding courses of the Kentucky River and its main tributaries and the widespread distribution of old river sands and gravels over the present uplands, bear testimony to the former base-leveled condition and subsequent rejuvenation by uplift of the country of which Franklin County forms a part. During their period of rejuvenation the streams trenched their channels deep into the underlying strata along the winding paths they had previously sketched out. There is some evidence pointing to the middle or late Tertiary as the time when the base-leveled condition was reached, and the early Pleistocene as the period of elevation and stream rejuvenation.

[10] Kentucky Geol. Survey. Series IV, Vol. II, Part III, 1914, pp. 15 and 37.

"Correlating the cutting of the gorge with the elevation of the northeastern portion of North America during the Glacial period, would make the gravels preglacial, and hence at least Pliocene in age.

"M. R. Campbell, who named these deposits 'Irvine' Formation in his report on the Richmand Quadrangle, considered them to be of probable Miocene [Neocene] age. It has seemed to the author of this present report, however, that they are not older than Pliocene. He has been led to this view largely by the finding of remains of extinct Pliocene or early Pleistocene mammals in such association with these gravels as to indicate that they are of the same age. The most extensive of these gravels and sands are found west of the river in the southern portion of the county. They are found here in the Cedar Run precinct, extending over into the Bridgeport precinct.

"This distribution would indicate a considerable change in the course of the Kentucky River in this region since preglacial times.

"These deposits are particularly abundant west of the Lawrenceburg pike and south of Elmoro.

"A conspicuous element in this deposit are the quartz pebbles from the Coal Measure Conglomerate, and the Keokuk-Waverly geodes. The former have probably been derived from that portion of the Kentucky River drainage occupied by the western margin of the eastern coal field, and the latter from the upper Dix River drainage."

In a trip made with Dr. W. R. Jillson through southern Franklin County into Anderson County in 1924 we noted at Alton a deposit of red sand 15 feet or more in depth that should probably be included in the Irvine Formation. It is on the divide between the Kentucky and Salt River drainage at an altitude of 820 to 840 feet. It is about four miles from the nearest point on Kentucky River and eight miles from Salt River, at its bend in the southwest part of the Frankfort Quadrangle. It is a rather coarse sand and appears to be a water rather than wind deposit. It seems to be preserved only in a narrow strip on the divide for about one-fourth mile south from the hamlet of Alton. We were informed by residents of Alton that it is the only deposit of its kind in that vicinity.

In the same trip we found that a network of old drainage lines connects valleys that are now tributary to Kentucky River with tributaries of Salt River. These old stream courses as shown by the Frankfort topographic map, are mostly below the 800-foot contour, and thus seem to be of later date than the deposit of sand. One of these channels passes within one-fourth mile east of this deposit and connects Little Benson Creek, of Kentucky River drainage, with the headwaters of Hammonds Creek, a Salt River tributary. Another channel at less than 780 feet crosses from the head of Little Benson Creek

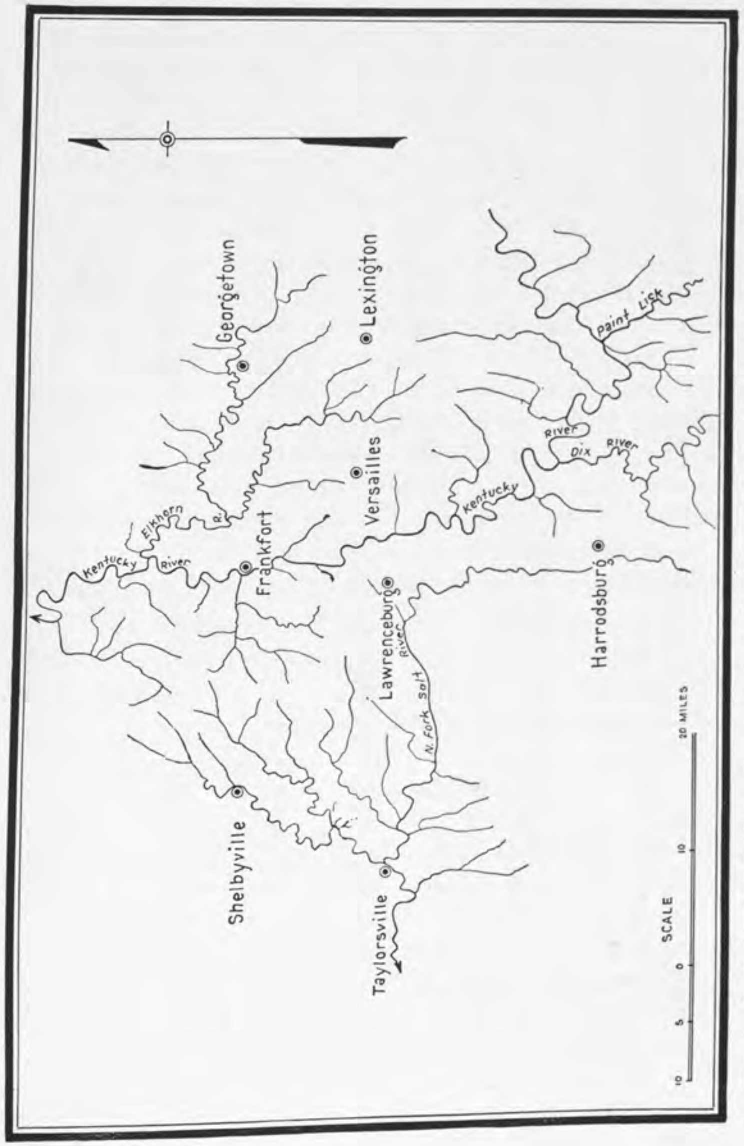


Fig. 1. Map showing capture of part of Kentucky River drainage by Salt River, near Lawrenceburg, Kentucky.

to the South Fork of Benson Creek, just north of the Anderson-Franklin County line. The beds of these channels are lined with quartz pebbles derived from the Coal Measure Conglomerate. They seem to mark the courses taken by tributaries of the Kentucky in an early stage of valley development. These tributaries seem to have drained a district now drained by Salt River. An important instance of stream deflection from the Kentucky into the Salt River drainage was noted by us a few miles farther south. The north-flowing headwater part of the North Fork of Salt River in Boyle and Mercer counties, is connected with Kentucky River by a shallow valley carrying fluvial material, which was the former line of discharge of this stream into the Kentucky. But Salt River, probably because of a more direct course to the part of the Ohio where it discharges, and one through weaker strata, has diverted this stream away from the Kentucky. In Fig. 1 is presented a map showing this stream diversion. These channels appear to be somewhat later than the Irvine formation, yet they date from a time prior to the main channeling of the Kentucky and Salt River. Whether of late Pliocene or of early Pleistocene age is as yet undetermined.

It is probable that at the time the Irvine formation was deposited the drainage at the present mouth of the Kentucky was at least 350 feet above the present river level, or fully 750 feet A. T. under present altitude relations.

The Ohio River Formation

Ashley noted the occurrence of this formation along the divide between streams flowing east into the Ohio or into Silver Creek, and those flowing west or south, in Harrison County and at scattered points in Washington County, Indiana. He appears to have considered the deposits marine, for he remarked:

> "In the meanwhile there seems to be a growing mass of evidence that the region occupied by the present valley of the Ohio River has been base-leveled in preglacial times, that sea deposits of limited thickness but of probably wide extent were deposited over the area, that differential elevation has since taken place and the present valleys of the Ohio and its tributaries in Indiana and Kentucky have since been carved out."

The formation consists mainly of sand, with considerable cross bedding and containing a few small quartz pebbles. The

sand is siliceous, with but a slight amount of iron stain. It ranges from pure white to brown and occasionally reddish color. It has been used as a glass sand and also in masonry. In places it carries inclusions of finer clayey material. There are also places where gravel is associated with it. Thus at an outcrop, on a ridge 2 miles southwest of Farabee, Indiana, it is described by Malott to be a cherty conglomerate at base, while the upper portion is mainly loose sand very much cross-bedded. It there reaches a thickness of approximately 50 feet. There and elsewhere in its exposures in southern Indiana it is thought by Malott to have the appearance of a beach formation.[11] The greatest thickness noted in Indiana is about 80 feet, on the crest of the ridge east of Buena Vista, in Taylor Township, Harrison County. Its lower limit there is 765 feet, or nearly 400 feet above the Ohio River. Its upper limit in Harrison County falls short 20 to 70 feet of covering the highest hills. It is placed by Malott at 935 feet A. T. The upper limits in Washington County, as determined barometrically by Ashley are nearly 1,000 feet.

Sand deposits are present in Meade County, Kentucky, in the sink hole district of St. Louis limestone. In two places where it is drawn upon commercially it is filling sink holes. One of these is at the pit of the Kentucky Silica Sand Company near Tiptop, Kentucky, where it has been opened to a depth of 50 feet, the other is a mile southwest of Guston, where its thickness does not exceed 20 feet. Its base in the pit near Tiptop is about 700 feet and in the one near Guston 670 feet A. T. The deposit in each place shows no evidence of having settled after deposition, as a result of the development of the sink holes, but seems to have been laid down after they had been formed. The country thus stood sufficiently high prior to the deposition of this sand for the development of a system of underground drainage, and also for a relief of over 300 feet to be developed on the surface. It appears, however, to have antedated the cutting of the trench of the Ohio River, which is 250 to 300 feet deep in its passage across the sink hole country of the St. Louis limestone. The topography of the district near the pit of the Kentucky

[11] C. A. Malott, Handbook of Indiana Geology, Ind. Geol. Survey, 1922, p. 134.

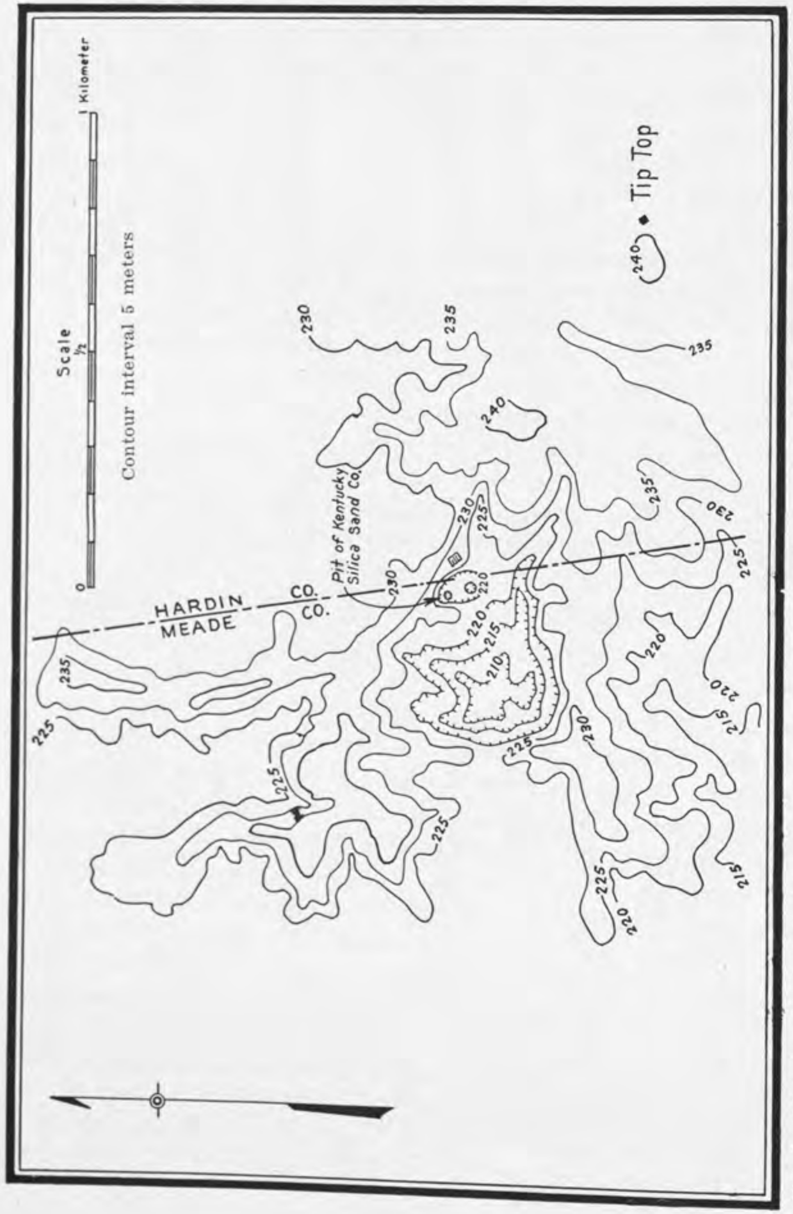


Fig. 2. Map showing topography around the sink hole in which the deposits worked by the Kentucky Silica Sand Company were deposited. Contours from Artillery Range Sheet 3, Camp Henry Knox, Kentucky. Altitudes in meters.

Silica Sand Company is shown in Fig. 2, taken from Artillery Map 3 of Camp Henry Knox, Kentucky.

In his report on the glass sands of Kentucky,[12] Prof. Charles H. Richardson quotes E. F. Burchard as of the opinion that the deposits at the pit of the Kentucky Silica Sand Company are of Tertiary age, but Richardson considers it a formation of Mississippian age, which he terms the Big Clifty (Cypress) sandstone, of Chester age. With it he includes deposits at Eastview, Solway, Big Clifty, Millerstown and Leitchfield.

An analysis of the sand at the Kentucky Silica Sand Company pit is reported by Richardson as follows:

Analysis of sand from pit of Kentucky Silica Sand Company:

	Per cent.
$Si\ O_2$	98.26
$Fe_2\ O_3$	0.43
$Al_2\ O_3$	1.09
$Ti\ O_2$	Trace
Moisture at 104 C	0.06
Loss on burning	0.26
Total	100.10

The following suggestions have been received from Charles Butts of the United States Geological Survey, in a letter of January 19, 1925, as to the mode of desposition of the sand deposits of the Ohio River Formation:

"As to the origin of the sand deposits in the vicinity of Muldraugh and in Indiana (Ohio River Formation) I have this suggestion to make: They may be cavern deposits exposed by erosion. They might have been derived from the Cypress sandstone which formerly extended over the region at no great height above the St. Louis limestone. The Cypress is a coarse friable sandstone, as shown in the railroad cuts in the vicinity of Summit station. The underlying St. Louis, Ste Genevieve, and Gasper limestones are the cavern forming strata of the region. That such an origin is possible I believe from the fact that sandstone waste, including good sized rolled boulders, is in places uncovered in limestone quarries where it was evidently deposited in pipes leading down from sinkholes to subterranean streams. Such deposits occur in central Pennsylvania, and a belief in their general occurrence under the right conditions is seemingly in accordance with sound theory. Such a manner of origin would explain the occurrences of such isolated deposits as those in Indiana and Kentucky at varying altitudes, and having no uniformly general relations to the rocks with which they are now associated. The sand deposit at Tip Top in actual association with sink holes seems to be in harmony with such an origin. Obviously such deposits could have originated at any time in the degradation of the region below the level of the Cypress sandstones. If such an origin could be invoked in the case of the Indiana and Ken-

[12]Kentucky Geol. Survey, Series VI. 1920.

tucky deposits it would permit their explanation without resort to such an extreme hypothesis as regional submergence, which apparently has nothing else to support it. Again this theory would account for the differences in altitude of the different sand deposits with respect to the altitude of the chert gravels.

"I do not feel in a position to discuss profitably the relation of conditions in the Upper Ohio Valley to those of the Indiana-Kentucky region. . . . I can only say this, that I would be disinclined to accept the idea of a general marine submergence except on the most compelling evidence, which is at present, I believe, wanting.

"I see no evidence whatever of a submergence after the topography had reached its present condition. Such a submergence would have been a marine one extending to the Gulf of Mexico and could hardly have failed to have left clear evidence of its occurrence somewhere within the submerged area."

Tertiary (?) Sand in Campbell County, Kentucky

A sand deposit is preserved along the great crest ridge between the Licking and Ohio rivers between Newport and Alexandria, Kentucky, at an altitude between 800 and 900 feet. The remnants preserved are only 10 to 30 feet thick. The deposit is a medium grade, brown, siliceous sand, strikingly in contrast with the stiff residuary clay capping the limestone formations in that region. It is exposed in a pit a mile east of Cold Springs and in cellars at Alexandria, and wells are in some cases obtained in it in these villages, and along the ridge between them.

Molding Sand Near Covington, Kentucky

West of the Licking River, directly back of Covington, Kentucky, there are deposits of a fine grade of molding sand at about the same altitude and of similar thickness to the sand on the ridge east of the Licking River, the lowest observed altitude being about 820 feet A. T. and the highest about 860 feet. This sand is covered by a glacial deposit, that shows a much higher degree of weathering than the Illinoian till of that region. No limestones are preserved in the glacial deposit, yet the chert which accompanies the limestone is abundant, and it probably was originally thickly set with limestone pebbles. This feature is mentioned since the underlying molding sand carries calcareous concretionary masses of remarkable size, some of the chunks being 18 inches in longest diameter, and 4 or 5 inches thick, which seem likely to have been formed by the percolation

of calcareous water from the overlying till. The trench of the Ohio is now cut to a level about 400 feet below the base of this sand and that east of the Licking. But that amount of cutting is of about the same order of magnitude as the 300 foot trench cut by the Ohio between New Amsterdam and Hawesville after the Ohio River Formation was laid down in Harrison County, Indiana. It is to be expected, therefore, if this sand on the borders of the Licking is a correlative of the Ohio River Formation, that it antedates the cutting of the gorges of the Ohio and Licking rivers. Drainage changes near Cincinnati, discussed below, seem to date from mid-Pleistocene time.

Lafayette Gravel

The part of the Ohio Valley below the sink hole district of St. Louis limestone, in Meade County, Kentucky, and adjacent districts, is characterized by deposits of polished waterworn cherty gravel, such as covers much of the Jackson Purchase in western Kentucky and adjacent parts of Illinois and Missouri at the head of the Gulf Embayment, and which is now commonly classed as Lafayette Gravel. The material is evidently fluvial, and shows transportation westward down the valley, and decrease in altitude in that direction. For part of the course the deposits are at a slightly lower altitude than is found a few miles back from the river on either side. Yet there are scarcely discernible limits to be assigned to the very shallow valleys occupied by the gravel deposits. Subsequent erosion has also reduced the old valley floor with its gravel coating to mere remnants. From the vicinity of Hawesville westward, the gravel caps the highest hills, and in some cases seems to have protected these hills from further reduction in height.

This gravel has been noted as far up the Ohio as New Amsterdam, Indiana, and the altitude there as determined by Malott is 735 feet;[12] at Stephensport, Kentucky, 700 feet, as determined by Malott, and 660 to 680 as determined barometrically by the present writer; near Hawesville, 625 feet, as shown by the Tell City topographic map. Below Hawesville the gravel is preserved only on hilltops, or in places where it has been redepos-

[12] Handbook of Indiana Geology, 1922. p. 134.

ited at lower levels than the original level of deposition. In southern Illinois, in the south part of the Brownfield Quadrangle, there is a small area where it appears to be preserved at the original level. With a capping of loess 10 to 25 feet thick it catches the 600-foot contour, so the gravel surface is but slightly below that altitude.

On the East White drainage in southern Indiana the gravel is reported by Malott to be up to 720 to 740 feet on Salt Creek, near Harrodsburg, about 700 feet near Shoals, and about 620 feet near Princeton, Indiana.

Studies have not been carried up Green River far enough to determine the extent and altitude relations of this gravel. It is known to cap hilltops as far up as northwestern Warren County. But so far as yet ascertained the deposits in this drainage basin are not above 600 feet, and the remnants may not represent the original surface, or the original place of deposition.

From about the 87th Meridian westward the gravel seems to have been spread over the entire interval between Green and Ohio rivers, and to some distance north of the Ohio and south of Green River. It is also widespread on hilltops in Henderson County, west of the mouth of Green River. The width of deposition from the 87th Meridian westward past the mouth of the Wabash appears to be not less than 30 miles. The width at Hawesville is about 6 miles, but farther up the Ohio it seems to be narrower. It is also narrower below the mouth of the Wabash, where the Ohio passes through the ranges of disturbed strata known as the "Ozark Uplift." Below these ranges the Ohio enters the Gulf Embayment.

In a discussion of the Pliocene history of northern and central Mississippi Shaw has shown that broad terraces formed by the Mississippi have definite relation to the Citronelle Formation of the Gulf Coast of known Pliocene age, as shown by its plant remains, the highest or Brookhaven terrace being corelative of the formation.[14] The highest altitude attained by the Citronella formation is about 550 feet. The Brookhaven terrace rises to this height in west central Mississippi, but its remnants farther north show a decline to about 430 feet in the vicinity of

[14]E. W. Shaw, Prof. Paper 108 H, 1918, pp. 125-163. See especially 155.

Fig. 3. Glacial Border and Other Features in Kentucky.

Memphis, Tennessee. Whether it becomes lower farther north before rising to about 600 feet at the head of the Gulf Embayment is not stated in this report, though the statement is made that scattered remnants were followed southward from Illinois through Kentucky, Tennessee and Mississippi to Vicksburg.

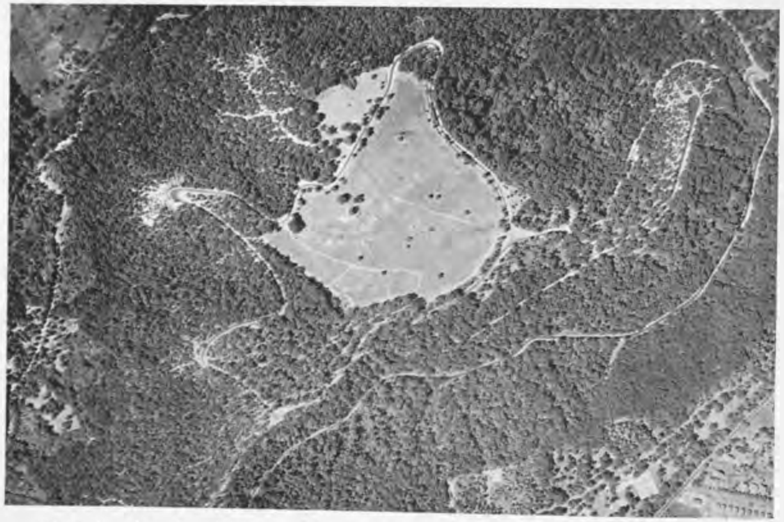


Fig. 4. Areal map of Jacobs Park near Louisville. The knob is upheld by lower Mississippian rocks while the plain surrounding is faced in the Devonian shale.

In the discussion of the features of southern Illinois, in the Murphysboro-Herrin Folio, published in 1912, Shaw called attention to a Tertiary conglomerate at 540 feet near the mouth of the Wabash, and to the presence of numerous quartz pebbles, apparently derived from such a conglomerate, in the basal portion of the glacial deposits of that region, and raised the question whether there may not have been northeastward drainage from that part of Illinois in late Tertiary time instead of drainage to the Gulf of Mexico. He stated that studies by A. E. Ortmann and others, of the mollusks, both terrestrial and aquatic indicate that in Tertiary time no large river flowed from the vicinity of Cairo to the Gulf of Mexico. He also stated that the Mississippi valley seems to be post Tertiary along the border of Illinois and Missouri, and is developed on the side of a structural and topographic trough. He dropped the matter with

this mere suggestion without attempting to locate the seaboard to which the Tertiary drainage may have led. In the present writer's opinion the most natural outlet for the drainage of southern Illinois, and adjacent lowlands in Kentucky and Indiana, was into the Gulf Embayment. If one restores the Tertiary filling to about 600 feet in these lowlands, as the remnants seem to warrant, there will be broad open passages into the Gulf Embayment, either along the Ohio or the Mississippi, across the disturbed and faulted area known as the "Ozark Uplift." Shaw's later paper, cited above, seems to give the lower Mississippi large volume in Pliocene times.

There is considerable uncertainty as to the thickness of the gravel deposits in their widely expanded areas, or the degree of erosion that preceded the original deposition, in the parts of the lower Ohio drainage basin that are now broken down to a low altitude. The remnants on the prominences are only a few feet thick, and deposits at lower levels are evidently of secondary nature, let down and redeposited in the course of later erosion. The Tertiary deposits at the head of the Gulf Embayment in western Kentucky and adjacent parts of Illinois and Missouri, have great thickness, 100 to 200 feet or more, but this may not have been the case north of the Ozark Uplift.

The present writer's studies of the Tertiary and pre-Tertiary gravel deposits of the Gulf Embayment are limited to a reconnaissance around the northern end in western Kentucky, southern Illinois and southeastern Missouri, and the verification of suggestions here made will depend upon wider and more thorough study. The upper limit of the gravel, as already indicated, is about 575 to 600 feet in southern Illinois, in south part of the Brownfield quadrangle, and it occurs up to similar height near Benton in southeastern Missouri. The upper limit along the Tennessee valley in western Kentucky and Henry County Tennessee is placed at about 600 feet by Bruce Wade.[15] The deposits are stated to be fluvial and to cover much of western Kentucky, and to decline from south to north with the present river, and to stand more than 200 feet above the present channel. Gravel deposits at lower levels are referred by Wade to the

[15]Bruce Wade: Gravels of west Tennessee valley, The Resources of Tennessee, Vol. VII, 1917, pp. 55-89, especially pp. 63-72.

Pleistocene and he has indentified four river terrace systems between the Tertiary deposits and the present flood plain, which he interprets to have been deposited in the course of the intrenchment of the Tennessee in the Mississippian formations of western Tennessee and Kentucky.

The largest gravel pit in western Kentucky is in an upper Cretaceous formation near Grand Rivers, between the Cumberland and Tennessee rivers. The gravel is here exposed for about a mile in length and 100 feet in depth. Its surface is about 450 feet above sea level. Features in this deposit seem to suggest a rise of water level during its deposition. The material is as coarse at the base as at higher levels. The lower part seems to have been laid down in a strong current along a river bed rather than in a pool as deep as the deposit is thick. The deposit seems to have been built up layer by layer to a height of 100 feet, by a rise of the water level. It seems to show that a river stage as low as 350 feet was followed by a rise to 450 feet. Whether by an overloaded condition, or by some other condition such as might arise by a sinking of the land remains to be determined. The distribution of this gravel is shown on the Geological map of Kentucky. The probable drainage of that time is suggested in Fig. 5.

Early Quaternary Fluvial Plains on Predecessors of Present Ohio

It has been known for nearly 50 years that the Allegheny River, one of the headwaters of the Ohio, has received large accessions from streams that in preglacial time had been discharging to the Lake Erie Basin.[16] It was also suggested by Spencer as long ago as 1881 that the upper Ohio region as far down as Steubenville, Ohio, was tributary to the Erie Basin in preglacial time.[17] The course of discharge was through the Beaver (reversed) and Grand River Basin of Ohio (see Fig. 5). About 10 years later the present writer, under the direction of Prof. T. C. Chamberlin, began a systematic study of the old flu-

[16]See J. F. Carll, Penn. Second Geol. Survey, Rept. III, 1880, pp. 1-10, 330, 439; Rept. III, 1883, pp. 1-147, 169-175, 219-406.
[17]J. W. Spencer, Penn. Second Geol. Survey, Rept. 1881, pp. 405-406.

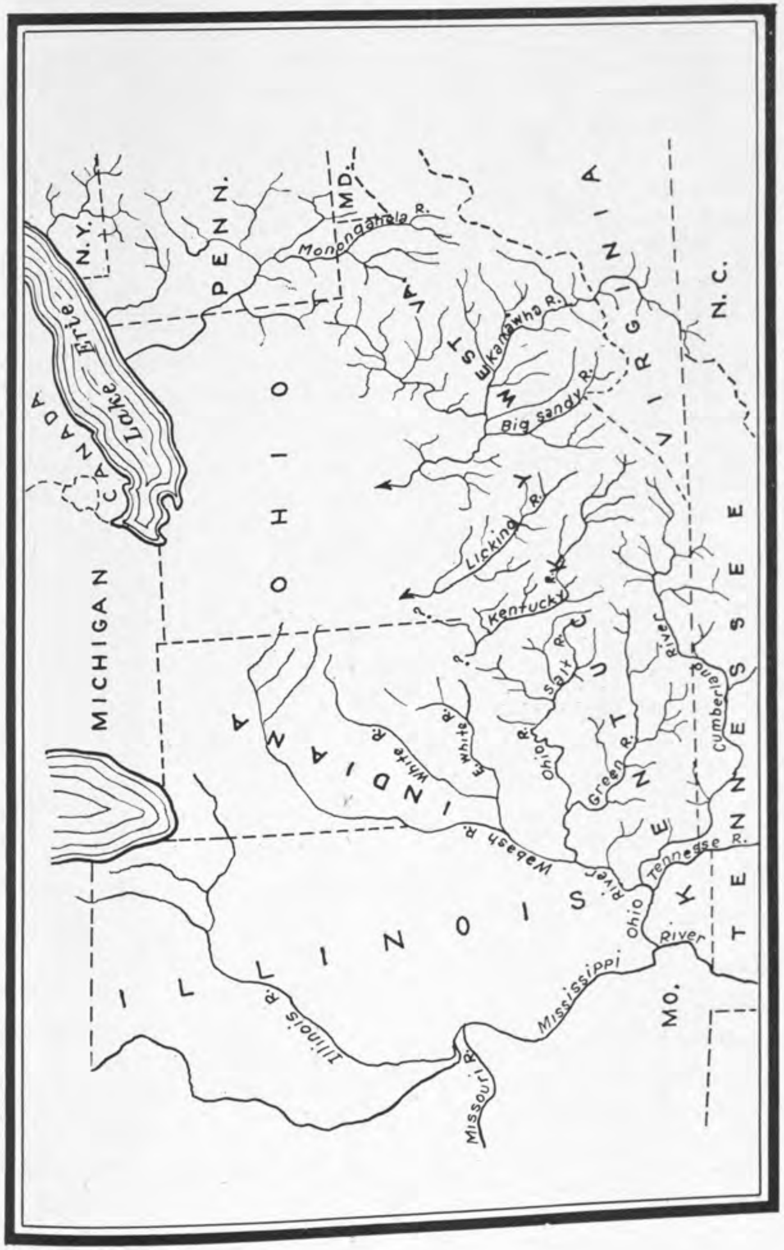


Fig. 5. Sketch map showing old drainage systems that were combined to form the Ohio River.

vial plains of the Ohio, the results of which appeared in scientific journals, and later in connected form in a monograph of the U. S. Geological Survey.[18] At about the same time Prof. W. G. Tight began studies of drainage features in southern Ohio, the results of which appear in bulletins of the scientific laboratories of Dennison University, and Professional Paper 13, U. S. Geological Survey. Studies by others have contributed important links in the chain of evidence that the Ohio drainage system is a combination of several systems that were formerly more or less independent. Among these may be mentioned I. C. White, P. Max Foshay, Gerard Fowke, Joseph F. James and G. F. Wright.

The old north-flowing streams that were united to form the Allegheny are known to have been blocked by an early Pleistocene ice invasion whose drift is present in northwestern Pennsylvania. This drift is found only upon and above the floors of the old valleys. Gorges cut in the old valley floors do not carry it. The floors and slopes of the old valleys thus indicate the character of the valley development in early Pleistocene time. The valley walls are not steep and the valley bottoms are relatively broad. The floors represent what Gilbert has termed a graded or gradation plane or profile, which results from a balance between erosion and deposition, the work of the stream being expended mainly in widening its valley. The slopes though broken down to an advanced degree, contrast strikingly with the indefinite borders of valleys of late Tertiary age, such as are occupied by the Irvine formation and Lafayette gravel. These early Pleistocene valleys not infrequently reach depths of 200 to 300 feet, and their bluffs or side slopes come out clearly on maps with 20-foot contour interval.

The filling of drift was so thick over the early Pleistocene valley floors in the upper Allegheny region that the present drainage has not cut down to them. But the lower Allegheny and its tributaries have cut trenches to a level 200 feet or more below the old valley floors, and there has been a corresponding depth of trenching on the upper Ohio. The depth increases as one passes southward toward an old divide near New Matinsville, a few miles south of Wheeling, partly because of the north-

[18]Glacial Formations and Drainage Features of the Erie and Ohio Basins, by Frank Leverett, Mon. XLI, U. S. Geol. Survey, 1902.

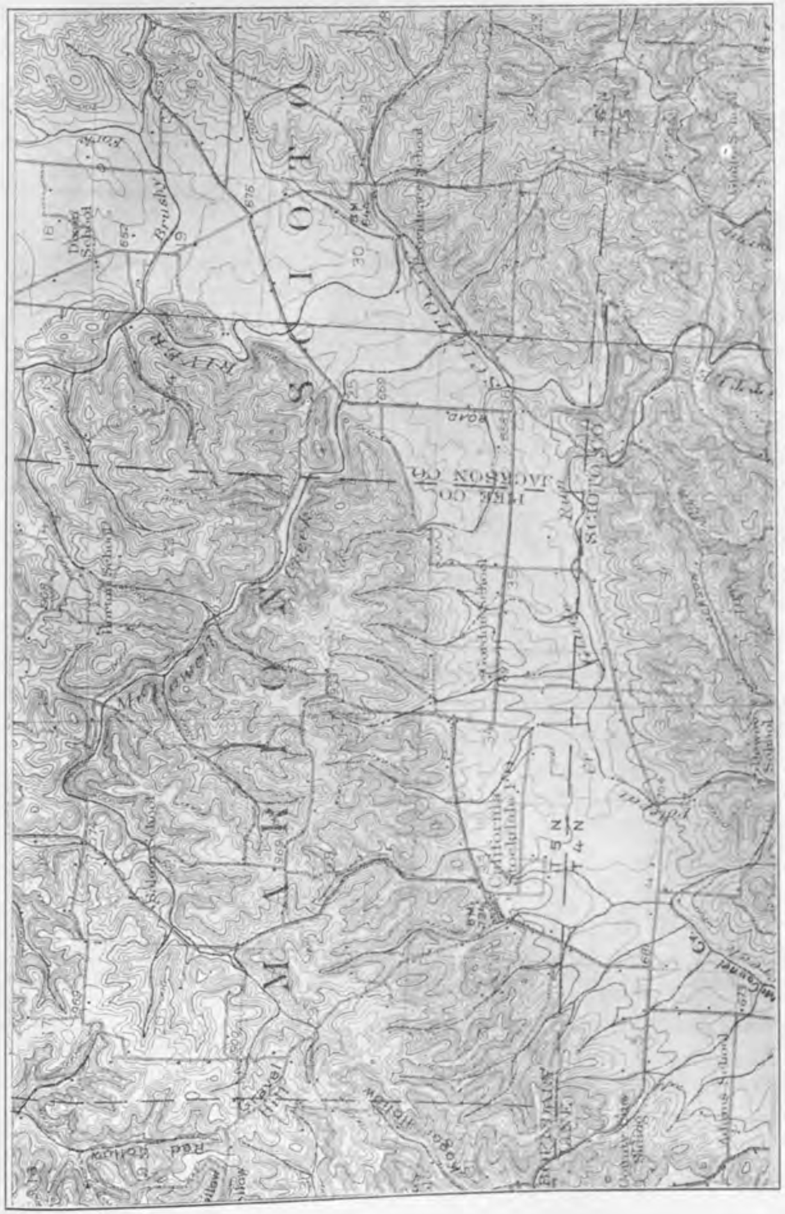


Fig. 6. Northeast part of Sciotoville, Ohio-Kentucky, quadrangle. A section of the old Kanawha valley, known as California valley, is shown. The highest remnants of a silt deposit in the valley stand above the 740 contour. The lack of control of present drainage by this valley is well illustrated by the course of Little Scioto River as here shown. Part of the removal of silt deposits seems to have antedated the initiation of certain drainage lines such as McConnel Creek and Glade Run, the divide between them near California being below 700 feet.

ward slope of the old valley floor and partly because of southward descent along the present river.

The next important old drainage system now embraced in the Ohio is that termed the old Kanawha system, the Kanawha River being its main artery. This drainage system has abandoned sections, Teay's Valley in West Virginia, the valley back of Ashland, Kentucky, and California Valley in southern Ohio, which show strikingly similar erosion features to those of the north flowing upper Ohio of known early Quaternary age. The abandonment of these sections must date back at least to early Quaternary time. The rock floor of the Teay's valley is about 650 feet A. T. or 150 feet above low water in the present Ohio at the line of West Virginia and Kentucky. It shows a slight descent when followed through the sections lower down, but is fully 600 feet where it opens into the Scioto Valley near Waverly, Ohio. In part of its course between Wheelersburg, where it leaves the present Ohio, and Waverly, the bordering bluffs are fully 300 feet in height (see Fig. 6). It is about as clearly defined in topographic maps of the Sciotoville and Waverly quadrangles as the present Scioto and Ohio valleys. Yet in spite of the great depth of this valley in southern Ohio the present drainage lines follow it to a remarkably slight degree, but instead make incursions into the bordering hills. This is due to the fact that the old valley was filled with silt to a sufficient height to slightly exceed that of low passes among the bordering hills. In Teay's Valley and in the valley back of Ashland the silt filling is so high that streams have turned away from these valleys and taken new courses into the present Ohio. The discussion of these silt deposits is taken up later. It is merely to be noted here that they are occupying sections of old drainage systems that were abandoned as far back as early Quaternary time.

The old Kanawha drainage system is thought to have received a southwest tributary which came into it near Waverly through the Scioto (reversed) and which headed in the knobstone hills east of Manchester, Ohio. The channel opened by this stream was more winding than the present Scioto valley, and short sections of its sweeping curves are preserved on the borders of that valley between Portsmouth and Waverly. It is a smaller

valley than the Scioto, its bottom being less than one-half mile in width. It corresponds closely in depth and general character to the valley of the old Kanawha, and was evidently completed in similar early Quaternary time.

Directly west of the source of this tributary of the old Kanawha is found the head of a small stream that followed the general course of the present Ohio from Manchester to Cincinnati. It, however, was more winding than the Ohio and short sections of its loops are found on the borders of the Ohio valley. One of these connects the lower course of Twelve Mile Creek with that of Ten Mile Creek near Oneonta, Kentucky. Another makes a detour south of Melbourne and crosses Four Mile Creek to the valley of its west fork and follows that down to the Ohio. The floor of these sections of the small predecessor of the Ohio is about 660 feet A. T. or 220 feet above the Ohio. Numerous quartz pebbles, probably derived from formations at the head of the stream are present on its bed. These abandoned sections show the stream to have been a small one, for they are but one-fourth to one-third mile in width. They are entirely consistent with a drainage line heading near Manchester. This was joined below Manchester by two other streams on the Kentucky side, Crooked Creek and Cabin Creek, which also head in the Knobstone hills of western Lewis County. The depth and general character of this valley are consistent with the north flowing upper Ohio and old Kanawha and its development may thus be put as far back as early Quaternary time.

The Licking River is known to carry a gradation plain of similar character to that of the drainage systems just discussed, but the present writer has not made a connected study of its valley. An abandoned section standing about 150 feet above the river was noted west of Milford, near the mouth of North Fork. For 2 or 3 miles below Grants Bend, on the lower course of the stream, a gradation plain is preserved, which in places occupies about half the width of the valley. Its altitude is nearly 200 feet above the stream, being 640 to 650 feet, by aneroid. It has a similar depth below the bordering upland. There is reported to be an abandoned channel of the Licking farther up than either of these, which crosses from Lower Blue Lick to Johnson Creek and follows down that stream to the present

river, but this was not personally examined, and its altitude is not known.

Between the mouth of the Licking and the mouth of Kentucky River is a section in which there appears to have been considerable complexity in the drainage history. The Licking may have maintained its old course northward from Cincinnati through the present Mill Creek Valley down to the time of the Illinoian glaciation. The enlarged Ohio also appears to have passed through and developed the lowland north of Walnut Hills in Cincinnati and joined the Licking River in this northward course. The present direct course on the south side of Walnut Hills, and from the mouth of Mill Creek to the mouth of the Great Miami, thus seems not to date from early Quaternary time.

There are valleys a few miles farther down the Ohio standing about 200 feet above the present river, in which the fluvial material is principally of white quartz pebbles. These valleys are much smaller than the present Ohio valley, the width being but one-fourth to one-half mile. These valleys were discussed by the writer in 1902[19] and the conclusion drawn that they pertain to tributary drainage, rather than to the main arteries. There are valleys crossing from the Ohio to Eagle Creek both above and below Glencoe, with cross valleys between them, making a complex system difficult to interpret, especially in the absence of topographic maps. There are other valleys winding about across the courses of the several tributaries of Big Bone Creek, which are equally puzzling. They probably were developed one after another by a series of diversions whose succession or order of occupancy depends on relative altitudes. But the differences are so slight that good topographic maps seem a necessary preliminary to proper interpretation. Whether or not they pertain to the main artery of drainage of this district at a time prior to the turning of the Ohio into its present course is perhaps not so significant a matter as the clear evidence that there was drainage for a long time, as far back as early Quaternary time, at a level about 200 feet above the level of the present Ohio in this part of its course. These channels are too small to seem to be referable to a stream the size of the Kentucky River, and thus

[19]U. S. Geological Survey, Monograph XLI, 1902, pp. 114-115.

cannot consistently be cited in support of a northeastward discharge of that stream from its present junction with the Ohio.

There are remnants of a gradation plane at about 200 feet above the river at the mouth of Kentucky River, and also at the mouth of Indian-Kentucky Creek, the altitude, determined barometrically, being about 610 feet A. T. They seem to be consistent with the system of old channels up the Ohio Valley just discussed. In all probability the drainage from the mouth of the Kentucky was down the present course of the Ohio at that time.

To what extent the deepening of the valley about 200 feet on the part between the mouth of the Licking and that of the Kentucky is due to the enlargement of the drainage area, and to what extent to uplift is a matter difficult to evaluate in the present state of knowledge. It seems probable, however, that a considerable part is due to this enlargement.

At a few places farther down the Ohio narrow remnants of an old gradation plain were noted at 175 to 190 feet above the Ohio at low water. Remnants of such a gradation plain were crossed on a road leading northward from Alton, Indiana, across Mill Creek to Little Blue River at 175 feet (barometric) above the Ohio, and on every one crossed waterworn pebbles were noted. Among them are quartzite, granite and greenstone pebbles. These also are present on lower benches, a quartzite 4 inches, and a granite and a greenstone each 3 inches in diameter being found at about 100 feet above the river. Back of Stephensport, Kentucky, on the road to Union Star a terrace 175 to 190 feet above the Ohio is coated with gravel in which a pink quartzite 3 inches in diameter, and two pebbles that appear to be weathered granite were found. The terrace remnant here is about 1,000 feet in width, but the gravel covers only a small part, like a bar. Chert gravel (Lafayette) occurs at much higher level back of this bench, at 300 to 330 feet above the Ohio, as previously noted.

The depth to which the lower Ohio valley from Hancock County westward, had been eroded in early Quaternary time is a matter on which features are not clear. The formations are so readily broken down that terraces representing old valley floors are not well preserved, and do not admit of ready identification. In view of the great breadth of the bottom lands, in places 10

miles or more, it seems not improbable that the valley had been broken down at least to the general level of these bottoms, about 400 feet A. T. In that case no terraces are exposed, and the old valley floor is now buried under later sediments. These sediments are discussed below in connection with the Illinoian stage of glaciation.

Extent to Which Ohio River was Developed by Pre-Illinoian Glaciation

As indicated above, it is evident from the relation of the old drift of the Allegheny and upper Ohio region to the early Quaternary fluvial plains, and its absence from the gorges cut in those fluvial plains, that the drainage system that produced these gorges, or inner trenches, began operation after that early glaciation. While not fully demonstrated, it seems highly probable that an early glaciation affected that region which is the same as the Jerseyan glaciation to the east of the Alleghenies, and that it is the first or second of the series of Pleistocene glaciations. It was determined by the writer in 1926 that the Illinoian drift extends beyond the Wisconsin drift in northwestern Pennsylvania, and also in eastern Pennsylvania and New Jersey.

From data above presented, it appears that the several abandoned sections of the old Kanawha drainage system, in West Virginia, eastern Kentucky and southern Ohio, are correlatives of the early Quaternary fluvial plains of the upper Ohio region. The cause for their abandonment appears to be somewhat complex but the time seems to be fully as remote as that of the drainage changes in the upper Ohio region which came as a result of the early glaciation just noted. There seems no reason to doubt that the drainage was deflected from its northward course into the Scioto basin to its present course westward along the border of Ohio and Kentucky as far back as the earliest glaciation. The natural effect of the occupation of the Scioto basin by the ice-sheet was to pond the waters of the Kanawha drainage to the height of the lowest col on the rim of its drainage basin in the district outside the ice-sheet. It is also necessary to take into consideration a possible, if not probable, lowering of the ice covered district by ice weighting, which would tend to expand the area of submergence outside. During

this time of ponding, or of submergence, silt deposits, up to 100 feet or more in thickness, were laid down in the valleys of southeastern Ohio, and adjacent parts of West Virginia and eastern Kentucky. The filling was so great in places that, when the ponded waters were drawn off, the streams took new paths across low passes among the bordering hills, and now only occupy parts of the old valleys. The newly established Ohio, however, seems to have made use of a southwest tributary of the old Kanawha to its source near Manchester, and then have followed down a small tributary of the old Licking to that valley in Cincinnati. Drainage in the new course may have attended, or have followed closely, the culmination of this early glaciation, the main contingency being a course unobstructed by the icesheet. It began long before the Illinoian glaciation, for Illinoian drift is widely present in gorges cut below the level of the early Pleistocene fluvial plains. That drift is present along the Ohio bottoms at numerous places between Manchester and Cincinnati, in the trench cut by the Ohio in its new course.

As already indicated, the enlarged Ohio seems to have flowed northward from Cincinnati to the Great Miami valley at Hamilton, Ohio, but it is very doubtful if it continued farther north. It seems to have taken the course indicated by Joseph F. James,[20] southward to the mouth of the Great Miami River, and thence along its present course below that point. This inference is sustained by the size of the river trench, and by the presence of Illinoian drift at low altitudes along it, there being conspicuous deposits near the mouth of Kentucky River as well as at points farther up that extend below present river level. It thus appears that the cutting of a trench about 1½ miles wide and fully 200 feet deep antedated the Illinoian ice invasion. The size of the valley trench on the lower Ohio is at all points such as to require the work of a large stream.

There thus seems little or no room to question the interpretation that the Ohio was given its present course below Portsmouth, Ohio, by the time of the culmination of the earliest Pleistocene glaciation. The Ohio must have flowed for a long period in its new course before the advent of the Illinoian glaciation.

Whether the river took its present direct course from the

[20]Jour. Cin. Soc. Nat. Hist. Vol. II, 1888, pp. 96-101.

mouth of the Little Miami to that of the Great Miami River as a result of the Illinoian glaciation or independently is not at present determined. The change to this more direct course may have come through the work of the stream and its tributaries in removing the narrow barriers to the east and west of the present mouth of the Licking River, and may have been accomplished at a time or times considerably earlier than the Illinoian glaciation. Possibly the barrier on the east was removed first as it is less prominent and narrower than that on the west.

The present Ohio valley, between Manchester and Cincinnati, is much more direct in its course than the small valley whose general course it follows. This naturally raises the question of the method by which the more direct course was developed. The ordinary way in which valleys are straightened, in cases where there has been no enlargement of the stream, is by the process known as sapping, in which the stream in its meanders strikes against both sides of the inclosed ridge until it makes a gap in the ridge through which the stream can make a direct passage, and abandon the meander. But where a stream is enlarged to many times its original size, as in this case, it is hardly to be expected that it would go through the long process of cutting a direct passage by sapping. Instead it more probably produced a ponding high enough to enable it to take a somewhat direct course across the strips standing between the meanders. It would thus be controlled only in a general way by the course of the valley of its small predecessor, and would soon come to have a direct course in keeping with its large volume.

Drainage Peculiarities Near Louisville

The Salt River drainage, and that of small streams entering the Ohio between Madison, Indiana, and Louisville, Kentucky, pass down a sloping limestone surface into a shale lowland. The Indiana part of this sloping limestone area has been termed by Malott the "Muscatatuck regional slope."[21] Its eastern border on the Kentucky side, and near the Ohio on the Indiana side, is nearly 900 feet, while its western border is only about 500 feet. On the western border of the shale lowland is the prominent Knobstone escarpment whose highest points reach 1,000 feet on

[21] C. A. Malott, Handbook of Indiana Geology, Ind. Geol. Survey, 1922, pp. 86-88.

the Indiana side and about 900 feet on the Kentucky side. Salt River now passes through the Knobstone escarpment before entering the Ohio. The escarpment is also traversed by North Fork of Salt River, by Pond Creek, and by the Ohio River in the part immediately below Louisville. The valleys of these streams show a *convergence* in passing through the escarpment that seems to favor the view that the drainage of the Kentucky part of the limestone slope and shale lowland was continued down the course of the present Ohio from a time that antedated the development of the present strong reliefs. It seems probable also that this old system embraced the area now directly tributary to the Ohio on the Indiana side. The southward decline in altitude shown by the Knobstone escarpment seems to favor this interpretation. Whether a larger area embracing the Muscatatuck and the headwaters of the East White also came south on the shale formation east of the Knobstone ridge is a matter for speculation. On the whole the features seem to favor westward drainage along the present course or one farther north rather than southward drainage along the east side of the Knobstone ridge. Below the Knobstone escarpment the Ohio seems to be following a preglacial course.

In the development of the present reliefs in the Salt River drainage area, and that of smaller streams to the north that seem to fall in the same section of the Ohio watershed, a large amount of relatively soft rock material has been removed, and broad areas now have an exceptionally low altitude. In the removal of this material the limestone at the base of the Devonian shale seems to have withstood dissolution to a remarkable degree, so that the slope of its surface has become the slope of the land. The uncovering of the limestone seems to have advanced gradually from east to west down this slope, and thus the eastern part has been exposed much longer than the western, and in consequence presents a higher degree of erosion. This is evident from an inspection of topographic maps in the Louisville district, and is a striking feature in the field along the entire length of the limestone slope. In the Louisville quadrangle the district west of a line running from Middletown past Jeffersontown to Floyds Fork at Seatonville has broad areas of flat land with rather slight stream dissection, while that to the east though but little higher

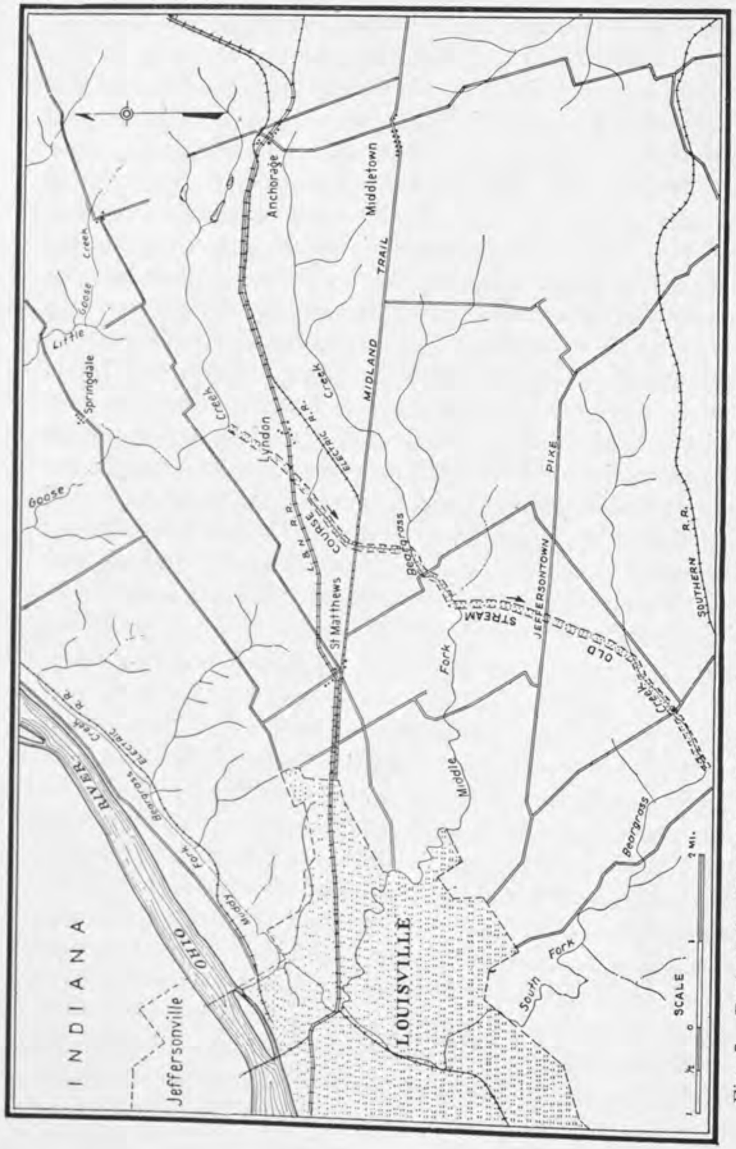


Fig. 7. Part of the Prospect and Louisville quadrangles. There is shown here the diversion of a former southwest-flowing stream (headwaters of Pond Creek) through successive captures by three northwest-flowing streams whose courses were more directly into Ohio valley, namely, Goose Creek, Middle Beargrass Creek, and South Beargrass Creek. The branch of Muddy Beargrass Creek heading near Warrick Villa has nearly reached the point of capture of a section of the old valley between Goose Creek and Middle Beargrass Creek.

shows more advanced stream dissection. The entire area of upland in the Prospect quadrangle in Kentucky below the 760 contour is remarkably flat. Harrods Creek and its tributaries are in steep walled gorges with flat areas setting in at the brow of the bluffs.

There appear to have been some shiftings of drainage effected in this less eroded part of the limestone slope. By reference to Fig. 7 it will be seen that a shallow valley or swale leads southwest from the bend of Goose Creek near the Military Institute past similar bends in the Middle and South Fork of Beargrass Creek into the Wetwoods district east of Prestonia tributary to Pond Creek. The present drainage does not follow this swale, but takes a more direct course to the Ohio valley by way of the three creeks just mentioned. These direct courses are through a higher tract forming the west border of the swale, but the advantage of direct drainage seems to have been great enough to enable them to work headward through this barrier and effect the diversions. The capture of the headwater part by Goose Creek is likely to have so reduced the old southwest drainage that very little erosion took place in the part below, and it was thus more rapidly diverted into the actively eroding drainage lines. The method of invasion of this swale seems to be repeated in a small tributary of North Beargrass Creek north of St. Matthews whose head is now working back eastward toward the swale at Warrick Villa. A further extension of only a half mile may be sufficient to capture a weak north tributary of Middle Beargrass Creek. It has already cut through the higher ground west of the swale and is descending to the Ohio valley by shorter course, with steeper gradient, than that by Middle Beargrass Creek.

Deficient Trenching on Streams Within the Blue Grass Region

The trenching on the Ohio and its tributaries seems to be a result of enlargement of the drainage area as well as a rise of the land. It may be difficult to determine to what degree each of these conditions has figured in causing the trenching. On the tributaries still other conditions than the deepening of the master stream are to be considered. Thus certain small tributaries of

the Ohio, and of the Kentucky and Licking rivers, in the Blue Grass region of Kentucky, are still flowing to a surprising degree at about the level of the old gradation plains, and are intrenched only for a few miles near their junction with the main streams. This deficiency in the development of trenches is not due to the presence of exceptionally resistant rock formations beneath these tributaries, for the formations, as on adjacent parts of the major streams, are of shale and thin bedded limestones. Dr. W. R. Jillson has suggested in explanation of this feature, that the small streams whose courses lie entirely within the limestone and shale areas of the Blue Grass region do not carry a sediment that will cut channels, sand or other sharp cutting material being at best a minor constitutent,[22] whereas the main streams are loaded with sand and cutting material.

The striking contrast between a main valley and tributary is to be found in the Frankfort, Kentucky, quadrangle. The Kentucky River at Frankfort has cut down to the 460-foot contour, but the Elkhorn directly east, at the junction of its two main forks, is 200 feet higher, or 660 feet, A. T. The Kentucky River is down to 480 feet as far up as Lock No. 5, east of Lawrenceburg, some 15 miles above Frankfort, and is in a deep gorge entirely across the Blue Grass region and well up into its headwaters. On passing up the Elkhorn by either fork 15 miles from the junction there is a rise of over 100 feet, to a level 300 feet above the corresponding part of the Kentucky River. The Elkhorn drainage thus has the advantage of good gradients in both these forks, for streams of such size. But these streams swing back and forth in very wide meanders in a broad wide-open valley, the only steep places being at points where a widening is in progress on the outer curve of bends. It is only in the lower seven or eight miles, falling in the Lockport quadrangle, that there is marked deepening, and even there the breadth of the valley is about as great as that of the Kentucky River. It is only in this part of the Elkhorn drainage that little tributaries come in through deep gorges, such as are found all along the Kentucky, where such tributaries enter the valley (see Fig. 8).

[22]Personal communication.

FIG. 8. DRAINAGE FEATURES IN PART OF FRANKFORT QUADRANGLE

Map of parts of Frankfort and Lockport, Kentucky, quadrangles, to illustrate deficient trenching on Elkhorn Creek in contrast to deep trenching on Kentucky River. This contrast, as suggested by W. R. Jillson, is probably due largely to lack of cutting material on Elkhorn Creek. The cut-off made by Kentucky River at Frankfort, as interpreted by Jillson, utilizes the former lower course of Benson Creek, west of Fort Hill.

Note.—The contouring of the two maps is not in agreement on their border west of Kentucky River.

There is a similar striking contrast between the main Licking valley and that of the South Fork, but topographic maps are not yet available for setting forth the conditions. The main Licking is in a deep trench throughout its course across the Blue Grass region, but the South Fork is in a wide open shallow valley nearly to its junction with the main stream. The North Fork, whose sources are in the edge of the sandstone hills, shows deep trenching as far up as the Lexington and Maysville pike south of Washington, but its headwaters, above Lewisburg, are not markedly intrenched. It is not unlikely that other factors than the amount of sand carried by this stream have accentuated the trenching on this valley, but the writer has not the data for evaluating them.

Features in Kentucky Referable to Pre-Illinoian (Jerseyan?) Glaciation

The occurrence of pre-Illinoian drift beneath the Illinoian in Ohio, Indiana and Illinois has been reported by several geologists, but definite deposits of till have not been reported in districts outside of these states, with the exception of a few exposures in western Illinois, between the Illinois and Mississippi valleys. Any erratics that have been found outside the limits of the Illinoian drift have generally been referred either to transportation by human agencies, or to flotation on blocks of ice in ponded waters outside the Illinoian icesheet. By some geologists the thick deposits of silt in the valleys of southeastern Ohio, and adjacent parts of Kentucky and West Virginia, have been assumed to be of Illinoian age, the ponding being referred to the blocking of the Ohio near Cincinnati by the Illinoian glaciation, as well as the blocking of the old north-flowing Kanawha drainage that led into the Scioto Basin.

Recent studies by Stuart Weller in western Kentucky, and by State Geologist W. R. Jillson and assistants in eastern and northern Kentucky, have brought to light the presence of erratics of glacial derivation in districts where they seem not to have been previously noted by geologists. Their presence in eastern Kentucky has been discussed by Jillson in recent papers,* and the

*Glacial Pebbles in Eastern Kentucky. Science, Aug. 1, 1924, Vol. LX, No. 1544, pp. 101-102. Also Glaciation in Eastern Kentucky. Pan-Am. Geol., Vol. XLII, pp. 125-32, Sept. 2, 1924; also Early Glaciation in Kentucky, Vol. XLIV, pp. 17-20, August, 1925. Also see pp. 123-141, Vol. 30, Ky. Geol. Survey, 1927.

suggestion offered that they may pertain to a very old glaciation.[23] Studies by the present writer in southeastern Missouri and southern Illinois in 1923 brought out evidence that a very early glaciation extended into that region.[24] The field season of 1924 was spent in northern Kentucky and adjacent parts of Indiana and Ohio in an endeavor to clear up the time and mode of deposition of these erratics. The studies are incomplete and the interpretations here presented are to a considerable degree tentative.

Distribution of the Erratics

There are three small areas in northern Kentucky where the erratics are somewhat common; elsewhere they seem to be very rare. One of these areas is in the knobstone hills and eastern coal fields in eastern Kentucky, a second area is on the knobs of Meade County, and a third is in the hilly district of the Ozark Uplift in western Kentucky. There is a fourth area near Covington where a deposit of till and gravel of very weathered appearance is present.

In the eastern district they have been found as far south as southern Lawrence and northern Morgan counties, a short distance south of Lat. 38°. They occur within the drainage basins of Big Sandy River, Little Sandy River, Tygarts Creek, and the North and Elk Forks of Licking River. They have a vertical range from as low as 720 feet on the Big Sandy to 986 feet on the knobs of western Lewis County. A bowlder in southern Rowan County is now at 720 feet, but it is in a sharp ravine in shale that is undergoing rapid trenching. The boulder may have been dropped on the top of the bluff capped by Cuyahoga sandstone which is over 800 feet, and fallen from there to its present position. Several have been found in the vicinity of passes between headwaters of Little Sandy River and those of Elk Fork of Licking River at about 850 feet, in such situation as to suggest that they may have been carried through these passes. Jillson has suggested that these southern passes may have been in competition with the col near Manchester as outlets for ponded glacial waters. They may also have served as outlets because of the extension of the icesheet over the pass at Manchester. The most elevated find of erratics is that of a large bowlder near Epworth in western Lewis County which is well up on the slope of a knob at 986 feet, and which is estimated by Jillson to weigh 16 tons. The topographic position as well as size of this erratic seem to be against its reference to flotation on ice blocks in ponded waters.

[23]Science, Vol. LX, 1924, pp. 101-102. Pan-American Geologist, Vol. 42, 1924, pp. 125-132.

[24]Bull. Geol. Soc'y America, Vol. 35, 1924, p. 69.

The weathered till and gravel near Covington is restricted to a narrow strip on the ridges between Licking River and Bromley Creek, about 3 miles in length, and one-fourth mile or less in average width, and a strip of gravel about a mile long on a ridge between Bromley Creek and Ohio River. The altitude of the deposits is between 800 and 900 feet, a few acres just north of Fort Mitchell being up to the latter contour, as shown on the West Cincinnati topographic sheet. Illinoian till is found on the same ridges, both south and west of these deposits, so they appear to lie within the limits of that glaciation. But as indicated below, the general aspect of these deposits is much older than that of Illinoian deposits. The weathered drift seems also to be restricted to elevated ridges, but the Illinoian is found down to low situations in the river gorges.

In the district southwest of Louisville there are features of somewhat puzzling character. The knobs of Meade County carry occasional small erratics up to 4 or 5 inches in diameter with an altitude as high as 800 feet, and smaller erratics were found in Bullitt County southeast of Kosmosdale up to over 700 feet. In addition to the erratics some of the knobs of Meade County seem to show evidence of water action of the kind produced by shore waves, the ledges being swept clean and spaces between scoured out to a depth of 3 or 4 feet. There are also large rounded local rocks that seem to be referable to similar shore work. All the erratics might easily be carried to their present position by Indians and other human agencies, but these other features lead one to hold as a working hypothesis the ponding of this region to sufficient height to cause the floating of the erratics from the ice covered districts to the north. Until the field has been more carefully surveyed this matter must be left in the present unsatisfactory condition.

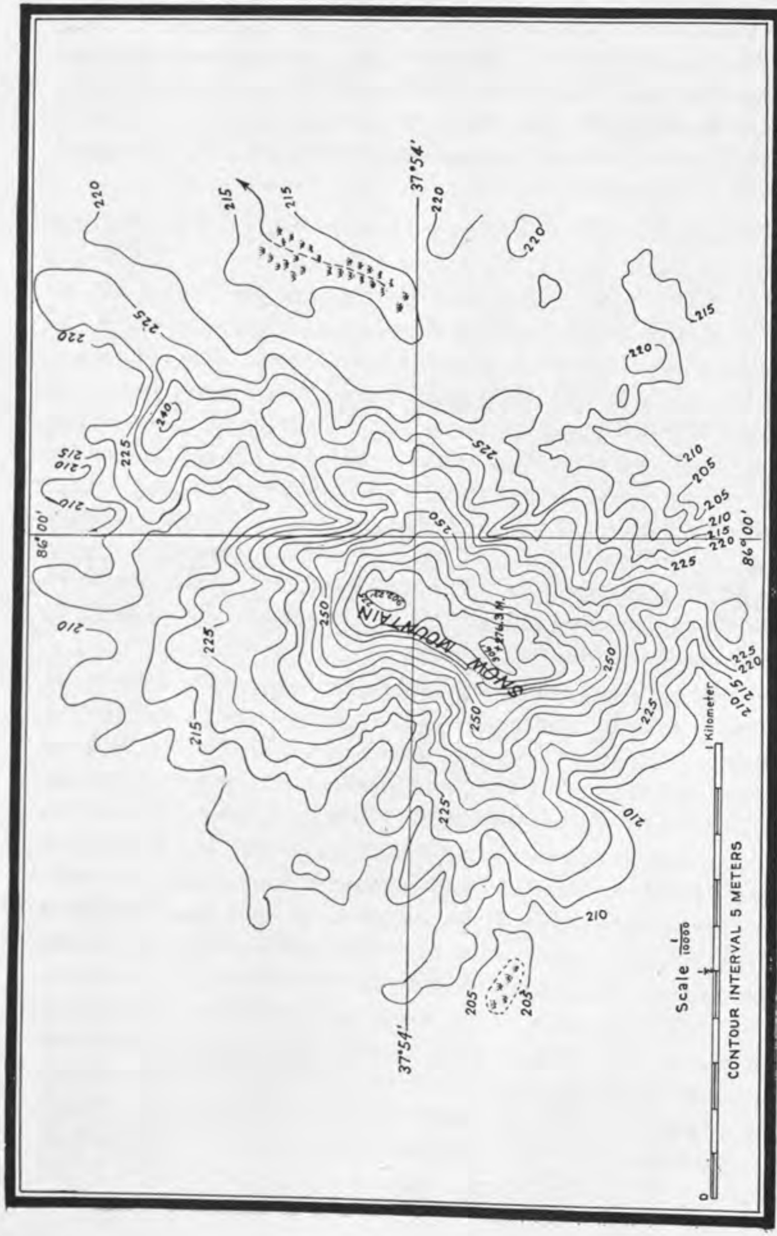


Fig. 9. Topography of Snow Mountain, a knob in eastern Meade County, Kentucky, that is thickly strewn with pebbles of glacial derivation carried up by man from the Ohio River valley. From Artillery Range Sheet 3, Camp Henry Knox, Kentucky. Altitudes in meters.

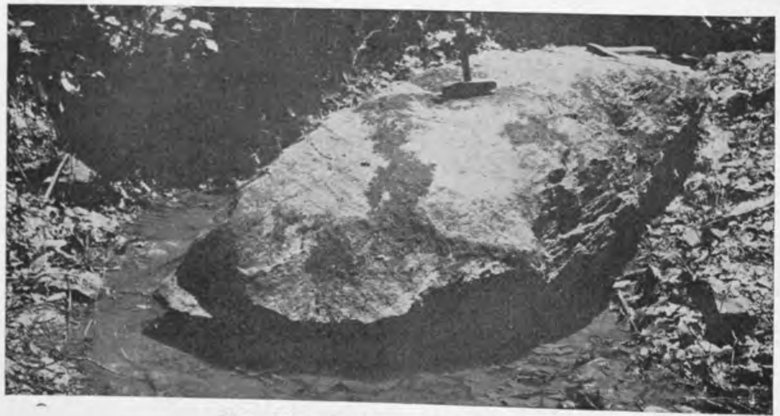
On the knob near Camp Knox known as Snow Mountain (Fig. 9) a large number of erratics are now to be found, scattered through the brush on the slopes, which were hauled up there from the Ohio Valley during the construction of buildings on the knob Their presence in the brush at some distance from these buildings is mentioned because future students unfamiliar with the work done there during the war may be at a loss to account for their presence.

In western Kentucky bowlders of quartzite have been found in a lowland back of the Ohio River hills near Sturgis, Kentucky, drained by Cypress Creek. They were found by James Henry of Marion, Kentucky, who had them removed to the courthouse square in that city. He states that they were found in the alluvial plain of this creek at an altitude of about 380 feet. The Ohio River has in relatively recent time flowed through this valley, or divided its waters between this valley and the present one. There is thus a possibility that these bowlders have been rafted in here on ice cakes in Ohio River floods. One of the bowlders is fully 3 feet in diameter, the other about 2 feet. Small pebbles of glacial derivation have been found in the Cypress lowland south of Spring Grove on bars in the valley about 400 feet A. T. These are within 2 miles below the place where the Ohio waters turned into the Cypress lowland, and were perhaps brought in by the Ohio.

Granite boulders were noted some years ago by Stuart Weller on the border of the Ohio in and near Carrsville, Kentucky. They are at altitudes of 380 to 400 feet. Small erratics were noted by the writer at similar altitudes in that vicinity in 1924. Two granites 8 inches in diameter were found near the Milford Bridge 4 miles east of Carrsville, and a greenstone slightly larger in the village. A bowlder located by Weller in the south part of the village is broken into several pieces, but appears to have been about 3 feet in diameter. These rocks are all above the level of present floods on the Ohio, but they may have been within their reach in glacial times. Their occurrence thus does not seem to demand the presence of the icesheet. At least the case would be much stronger if the erratics were found outside the limits of probable river action. An assistant of Weller, Ben Cox, has reported to the writer the finding of small

Topography in Vicinity Epworth Boulder

Excavation of Portion Epworth Boulder



Side View of Farmers Boulder

LARGE EASTERN KENTUCKY GLACIAL ERRATICS

Photos by W. R. Jillson.

End View of Farmers Boulder

Some Fragments of Epworth Boulder

Excavation of Epworth Boulder

LARGE EASTERN KENTUCKY GLACIAL ERRATICS

Photos by W. R. Jillson.

erratic pebbles about 12 miles southeast of Carrsville, near Salem, Kentucky, but it remains to be determined whether they were carried there by human agency. The locality is well outside the reach of river floods.

A very few instances of the occurrence of small erratic pebbles in the Blue Grass region of Kentucky have been reported by members of the Kentucky Geological Survey, one being in a sink hole a few miles northwest of Frankfort. The significance of such sporadic cases remains to be determined.

Degree of Weathering of the Erratics

The erratics of eastern Kentucky appear to have an average degree of weathering somewhat greater than that of Illinoian drift pebbles. There is usually a weathered rind in granites and greenstones, extending to a depth of one-eighth to one-fourth inch and some kaolinization of the feldspars (See Appendix 1). None of the soluble classes of rock are present, though such rocks are likely to have been present in abundance in the original deposit, since the icesheet passed over extensive limestone formations north of this district. Of the two large bowlders, the porphyritic granite gneiss near Epworth, and the schistose quartzite near Farmers, the former was deeply disintegrated, and apparently had been materially reduced in size by exfoliation. The schistose quartzite seems to have been reduced by exfoliation, but is otherwise well preserved.

In the weathered drift on the ridges back of Covington, not only is the finer material deeply weathered, but also the included stones, of which a large number were broken by the hammer to determine the depth of disintegration. None were found which present an appearance as fresh as is commonly displayed by pebbles of similar kind in the neighboring exposures of Illinoian drift. In places where the deposit is 12 to 15 feet thick no limestone pebbles remain in it, but there are cherts that serve to indicate the former presence of limestone pebbles. The writer has learned from Prof. T. C. Chamberlin that he and Prof. R. D. Salisbury, some 40 years ago, made a drive past some of the exposures of this old drift, on or near the Lexington pike, and were strongly impressed with its highly weathered condition. It seemed to them very unlike the ordinary drift of

that region. The same impression was conveyed by Prof. N. M. Fenneman and Prof. Charles Richardson each of whom visited these sections with the present writer in 1924. In the discussion of the deposits of sand found on ridges each side of the

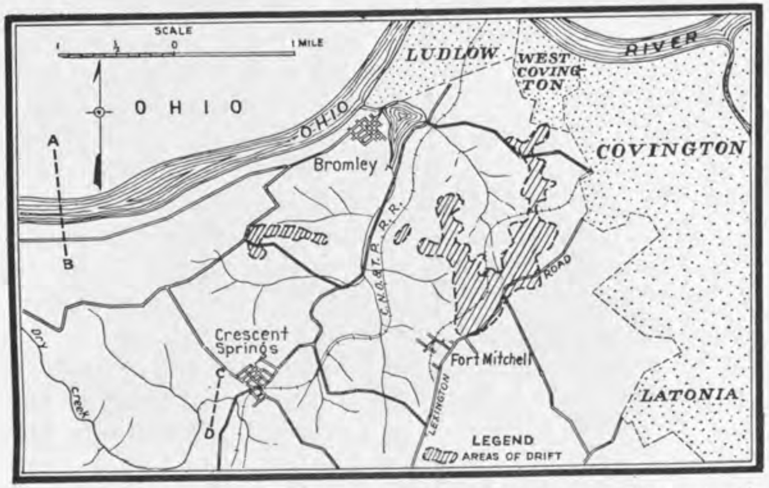


Fig. 10. Areas of old drift near Covington, Kentucky. The areas are inclosed by dashed lines. The map also shows the place at A- -B, near Anderson's Ferry, where Ohio River has cut an old divide. It also shows capture of old headwaters of Bromley Creek by Dry Creek at C—D, by Crescent Springs. This was effected when the stream was at about 760 feet at place of capture.

lower end of the Licking Valley it was noted that those deposits which underlie this old drift carry large calareous concretions that probably were formed by calcareous waters percolating down from the overlying till. That process appears to have gone on until the limestone material in the till had been completely removed.

The preservation of this old drift only on the narrow dividing ridges of this locatlity is, in keeping with its weathered condition, in favor of its being of pre-Illinoian age. It is a singular circumstance that its apparent south limit and that of the Illinoian drift should be so nearly coincident. Such coincidence, however, may be restricted to this one place, on each side of which the limits may be widely divergent. This old till may also prove to fall short of the limits of the glaciation it represents, which is not the case with the Illinoian till.

The erratic pebbles on the knobs in Meade County seem on the whole to show a less advanced degree of weathering than those in easern Kentucky, or those in the weathered till near Covington. This may be partly because of the peculiar topographic and drainage conditions on these knobs. The pebbles in eastern Kentucky were mostly in valleys or low places where they are likely to have been imbedded in the alluvium and kept in a damp condition for much of the time since they were brought in. Those in the till and gravel deposits near Covington, though in a prominent position with fair underdrainage, were under conditions favorable to dissolution. It is a common observation that stones imbedded in the drift, in each of the drift sheets, show a more advanced state of decay than those lying on the surface. The pebbles on these knobs are to a large degree surface pebbles which probably have been in a dry condition most of the time since they were brought in. Even under this condition the limestones, which in all probability were numerous at the time of deposition, have all been dissolved. The writer feels that there is so much to be learned as to relative degrees of resistance to decay offered by the various kinds of rock represented in the drift under various conditions of exposure that it would be well to withhold judgment as to the ages of the erratics on these Meade County knobs. Further, as to the Illinoian age, they are not favorably situated for being classed as a dependency of the Illinoian drift, because of their high altitude and their distance from the border of that drift. There is an interval of 35 miles between the border of the Illinoian drift at Jeffersonville, Indiana, and the nearest of these knobs, Snow Mountain.

Turning now to the erratics in western Kentucky, it was noted with much interest, as well as some surprise, that the two quartzite boulders from the alluvial plain of Cypress Creek although in a topographic position that would favor their deposition in relatively recent time, are not only of glacial derivation, but are weathered to a remarkable degree. They present a dark colored scaly surface similar to that of weathered granite, and surface alteration to a depth of one-half inch, but the rocks are a white glassy quartzite. In this case the imbedding in damp alluvium may be the cause of such exceptional alteration in a rock that ordinarily withstands surface decay. The granite erratics near Carrsville show no marked degree of alteration, but on the contrary look very similar to surface boulders of this kind on the Illinoian drift.

Derivation of the Erratics

Among the erratics there are only a few kinds that are from formations of restricted extent. Granites are so widespread and present such a variety of character even in a single outcrop that there can be no certainty of referring rocks of this class to the present ledges from which they were derived. The same is true of the wide variety of rocks included under the general term greenstones. But certain quartzites and conglomerates have peculiarities that are found only in restricted areas. Other rocks are confined to definite localities. Among the peculiar erratics of eastern Kentucky is the bowlder of schistose quartzite found at Farmers in southern Rowan County, and a norite gneiss found in Lawrence County. Chips from these and from the large granite gneiss boulder were submitted to Director W. H. Collins, of the Geological Survey of Canada, with the request that he report upon the probable location of the parent ledges in that country. Director Collins on December 2, 1924, forwarded the memorandum by Dr. J. F. Wright, of the Canada Geological Survey, given below:

Memorandum to Dr. W. H. Collins, Director, Geological Survey, by J. F. Wright, re-Specimens of Pre-Cambrian rocks from boulders in Kentucky.

Norite gneiss, No. 5. This specimen is typical of a phase of the Buckingham Series, as described by Dr. M. E. Wilson. The distribution of the hypersthene phase of this series as known at present in the Canadian pre-Cambrian, is limited to the district east of Ottawa, and north of the Ottawa and St. Lawrence rivers. Dr. Wilson says that, except for the limonite stains, he can duplicate this specimen in his collection of Buckingham area specimens, but he has not written his reports on this area, and does not care to break his collection. Anorthosite-gabbro intrusives are abundant in the Adirondacks.

Schistose quartzite. This specimen is similar to phases of the Grenville quartzite of the Ottawa-St. Lawrence valley, or of the Adirondack Mountains. West of Lake Superior the Seine series of Rainy Lake, or the Wannipigon series of southeast Manitoba are the only known series with rock types similar to this specimen.

Gray porphyritic granite-gneiss. This is a specimen of a very abundant and widespread rock-type in the Canadian pre-Cambrian. It

is particularly abundant in the Laurentian Highlands and the Adirondack Mountains. This specimen could be duplicated in almost any 20-mile square map area in the southern part of the Canadian pre-Cambrian shield.

Conclusions. Since hypersthene-bearing rocks are not widespread in the Canadian Pre-Cambrian, and the schistose quartzite and porphyritic granite-gneiss outcrop abundantly in the same area where the norite gneiss is known to outcrop, it is reasonable to conclude that all three specimens came originally from the same general district. With our present knowledge of the limited distribution of this norite type of intrusive to the Ottawa-St. Lawrence valley, and possibly in the Adirondack Mountains, it is concluded that these boulders were carried from some point northeast of a line from Ottawa to the southwest side of the Adirondack Mountains, and very probably from the area in Quebec between Ottawa and Quebec City.

While the data and conclusions presented by Dr. Wright place the probable source of these erratics farther east than the present writer had anticipated, there seems to be no opposing evidence in the topographic relations, for the icesheet would have had free passage over relatively low country to the west of the Adirondacks and the tableland west of the Alleghenies, into the middle part of the present Ohio drainage basin and eastern Kentucky.

From the vicinity of Covington, Kentucky, westward, quartzites and jasper conglomerates are found, usually in the form of boulders, but also as small stones, that appear to have been derived from the Huronian formations in the part of Canada east of the Superior Basin. The quartzites found near Sturgis in western Kentucky seem likely to have that source. The smaller one carries small pebbles, or coarse grains, one-eighth inch or more in diameter, with bluish color like those so common in the Huronian conglomerate. The white glassy quartz grains and pebbles in these boulders are also a common feature in the Huronian conglomerate. The phase of this conglomerate with conspicuous red and brown jasper pebbles is very common in the Illinoian drift from the vicinity of Covington, Kentucky, westward to the limits of that drift in southeastern Iowa. A quartzite in which a few small pebbles of red jasper appear and which seems referrable to the same Huronian area has been noted among the scattered boulders in southeastern Missouri that lie outside the limits of the Illinoian drift. There thus appears to have been a broad radiation of the ice in both glacial stages after it passed over this Huronian area. The distribution of the

jasper conglomerate is such as to show that the ice passed through the Lake Michigan basin and also through the Lake Huron basin. Specimens have been noted by the writer on Beaver Island in the north end of the Lake Michigan basin.

That the crystalline erratics in Kentucky are from Canada and of glacial derivation thus seems well established. The only point in question seems to be that of the extension of the icesheet clear to the several localities in which they occur. This leads us to consider next to what extent ponding or submergence may have been effective in scattering the erratics over districts outside the limits of the icesheets; also to what extent they may have been carried by streams.

Rafting of Erratics by Ponding, Submergence, and Stream Action

Ponding as here understood is the flooding of a district outside the ice border, whose drainage had been toward the icesheet, to a level high enough to give the waters escape across passes on the divide into another drainage basin. Submergence is here understood to involve a depression of the land sufficient to allow the sea to cover it, or instead to be of such character that the drainage was obstructed sufficiently to submerge large areas that had been well drained. Ponding does not depend upon diastrophism but submergence does. Rafting by stream action is understood to be transportation on blocks of river ice in winter or spring freshets, the rocks having either fallen on the ice or become otherwise attached to it.

The ponding of the old Kanawha drainage system to sufficient height to give an outflow into the Licking drainage at the headwaters of Little Sandy is estimated by Jillson to be about 850 feet. The old col near Manchester seems to have been no higher. It thus appears that so far as this divide is concerned the ponding need not have reached a greater height than 850 feet. This is 136 feet lower than the level at which the large boulder near Epworth in western Lewis County is found, and which is in the headwaters of the North Fork of Licking River. The lower course of the Licking, however, appears to have been invaded by the icesheet, at least to the position of the old drift west of Covington. As the river at that time appears to have

continued 25 miles farther north this invasion of the icesheet is likely to have ponded waters in the Licking drainage basin to sufficient height to cause outflow westward into the Kentucky drainage basin. The general elevation of this divide is known to be somewhat higher than that of the passes on the divide between the old Kanawha and the Licking. It seems to be fully 900 feet at all points. The only part covered by a topographic map is the Beattyville sheet, and this has a contour interval of 100 feet. It however covers the Devonian shale lowland on which the altitude is generally lower than on the Silurian and Ordovician limestone formation to the north, but an examination by W. R. Jillson shows that the divide there is about 930 feet. It thus appears not improbable that flooding in the Licking basin extended to fully 900 feet but not to 986 feet, the height of the Epworth boulder.

The divide between the Licking and Kentucky drainage basins is likely to have produced a higher ponding than could have been produced in drainage systems farther west by the invasion of their lower courses. In case the lower course of the Kentucky was invaded by the icesheet at this early glacial stage the flooding need not have reached a greater height than 800 feet to have given outflow westward into the North Fork of Salt River in southern Anderson County through a network of channels connecting the two drainage systems. Passes of similar altitude between Salt River and Green River drainage would have afforded discharge into the latter drainage in case the lower end of the Salt River drainage were ice covered. The invasion of the lower end of the Green River drainage basin could have caused only a very slight ponding to reach passes that would carry the water into the Cumberland and thence to the Mississippi Valley and Gulf of Mexico.

The suggestion that a marine submergence extended into this region in Pleistocene time came with the observation of features indicating wave work or strong scouring by water action, on the tops of the knobs in Meade County, Kentucky. That this scouring may have taken place in a glacial stage was suggested by the presence of scattered pebbles of glacial derivation on the crests and slopes of the knobs. The knobs thus may have served as lodgment places for drift-laden ice blocks. That the water

was not held at this height by a land barrier to the south or west was inferred from the fact that the knobs stand higher than the general elevation of these divides, and considerably above the low passes on them. An even-crested part of the divide between Ohio and Green rivers in the vicinity of Garfield is 780 to 800 feet, or slightly lower than the scoured ledges and erratics on the knobs. That such scouring may have taken place by water action within an icesheet is a matter that merits consideration. Its application in this case will depend on the determination that the icesheet covered the knobs in question. This is a matter of uncertainty at present. On the other hand the proof of a marine submergence will depend upon corroborative evidence of such submergence in the surrounding country. This has not as yet been investigated sufficiently to warrant any definite conclusions.

The extent to which erratics may have been transported down valleys by the large streams has already been suggested in the discussion of those of western Kentucky. Transportation of that sort is not restricted to glacial stages. It thus differs from the definite valley trains of glacial gravel such as were developed by streams that led away from the border of the icesheet and are very conspicuous in connection with the last or Wisconsin drift.

Age of Deposits in Abandoned Sections of the Old Kanawha

There are two distinct classes of deposit in these old valleys. At the base there is the river rubble of the old valley floor with some associated sand. This rubble includes rocks from the crystalline formations of the New River district, which is tributary to the Kanawha River, as well as those of less distant derivation. These have been recognized in the abandoned section in southern Ohio as well as in those in West Virginia and Kentucky. The sand is deeply weather-stained, and thus strikingly in contrast with the overlying blue silt. It is referable to the same early stage as the fluvial plain of the old river which as shown above antedates the trenching made by the present Ohio River. The sand and river rubble form a relatively thin coating on the old rock floor, usually less than 10 feet.

The silt deposits which cover these river deposits range in thickness from a mere trace to a maximum of about 100 feet.

They have usually been referred to the settling of fine material in ponded waters, but one writer considers the silt merely a flood plain deposit of the Kanawha River.

The variations in thickness which the silt deposits present are no doubt largely due to the erosion which they have suffered. There are only a few places where they have not been attacked and partly removed by the present drainage lines. The amount of this erosion it is thought may be used as a determining factor as to the time of deposition. It may thus be feasible to determine whether they were laid down in ponded waters of the Illinoian stage or at an earlier stage of glaciation. Or it may be possible by this method to separate deposits laid down in the Illinoian stage from those at an earlier stage, if both are present. The present writer has as yet given these deposits too little attention to speak with confidence on this subject. Enough has been seen however to give him the impression that the first and highest deposition of the silt occurred in an early Pleistocene stage. There may have been considerable deposition in the Illinoian stage, and there seems also to have been some slack-water depositions in parts closely connected with the Ohio valley as late as the Wisconsin stage. The Sciotoville Ohio-Kentucky quadrangle is thought to afford illustration of such deposition in two or more stages. Thus in the vicinity of California (Stockdale Postoffice) the silt is preserved in narrow terraces on both sides of the valley at about 740 feet. (See Fig. 6.) Its depth in wells a mile east of the village is 100 feet. Water is obtained at that depth in the sand of the old Kanawha River. There is also a silt filling to a level between 720 and 740 feet in a pass between this valley and the Scioto, directly west of Purdy Corners, 6 miles south of California. Both valleys thus appear to have had a silt filling to about that height. A silt filled pass southwest of Harrisonville catches the 740 contour, and the silt is found to similar height in other passes and in recesses of valleys in this district. Yet in spite of this evidence of an original filling to about 740 feet the present surface of the silt deposits is generally below 700 feet, and that too at places where there are now divides between the drainage lines. Thus the divide between Glade Run and McConnell Creek near California is widely opened below the 700-foot contour. Features of this sort

suggest that the present drainage lines date from a filling at Illinoian time which reached about 680 feet, and that the removal of silt down to or below this level was effected by a pre-Illinoian drainage system whose limits were different from those of the present drainage.

In the south part of the same quadrangle, along Little Scioto River, there are broad silt filled flats below the 600-foot contour which seem to have been developed as slackwater deposits in connection with the building up of the Wisconsin valley train on the Ohio. These silt flats fill a valley that had been cut to about the same depth as the Ohio in pre-Wisconsin time. It is not unlikely that the erosion had reached the full depth in pre-Illinoian time.

An excellent section of the silt deposits, extending into the underlying sand of the old Kanawha River, is afforded by a cut on the new line of the Chesapeake and Ohio railway immediately north of Harrisonville (Minford) in the central part of the Sciotoville quadrangle. The upper 15 feet is a somewhat pebbly clay of yellowish brown color, thoroughly leached as well as oxidized. The pebbles are very irregularly distributed, and were perhaps brought in by wash from the bordering hills, as they seem to be of local rocks and not much waterworn. Below this is a deposit of blue laminated calcareous clay 30 feet thick, in which no pebbles were noted. Under this clay is a deposit of red sand of the old Kanawha, which in places is cemented by iron into hard ferruginous layers. The top of the cut is about 700 feet, thus making the surface of the old Kanawha sand about 650 feet A. T. The cut does not reach the bottom of the sand at 10 feet, but rock outcrops in ravines nearby at about 635 feet A. T.

Silt Filling on Other Valleys

The silt filling on other old valleys in neighboring parts of Ohio and West Virginia is of similar character to the filling on the old Kanawha. A number of displacements of drainage lines seems to have taken place as a result of the filling of the valleys to the height of the low passes between them. This matter is one that seems not to have been well worked out by previous students, or to have been given the consideration that it merits.

Now that topographic maps are available it will be important to give the drainage history and the deposits in the valleys a careful analysis.

The dislocation, or diversion of the tributaries of the old Kanawha into new courses, appears, like the shifting of the Kanawha itself, to have taken place in early Quaternary time. The valleys which have been opened in the new courses seem to have done an amount of work comparable to that accomplished by the Ohio in proportion to the size of the respective drainage lines. The great drainage changes thus appear to be pre-Illinoian.

Scattered Erratics in Southeastern Ohio

In the course of the present writer's studies in this district in the 1890's his attention was frequently called to the presence of small erratics at considerable distances outside the limits of the till. Dr. H. L. True of McConnelsville had collected a large number of erratics ranging in size from 6 inches in diameter downward on the uplands around that city at a distance of 20 to 30 miles outside the border of the till, and at altitudes up to 1000 feet above the sea. Prof. W. G. Tight also reported the widespread occurrence of such erratics in the part of Ohio which he investigated. At the time of these studies the writer was disposed to refer their presence in this region to the work of Indians or other human agency. But since erratics have now been found in Kentucky at still greater distances outside the border of the till, and of a size entirely beyond that which is referable to human transportation, it seems well to look into the question of the mode of deposition of these small erratics noted in southeastern Ohio.

Character and Position of the Illinoian Drift Border in Kentucky

Although Illinoian drift is found on the north bluff of the Ohio opposite Louisville, Kentucky, no trace of it was found on the south side for about 15 miles up the valley from the city limits. The border of the Illinoian icesheet seems to have reached the bluffs on the Kentucky side no farther south than the valley of little Huckleberry Creek in western Oldham County. A few small pebbles of glacial derivation, 2 inches or

less in diameter, were found along the road that follows its south bluff from Harmony Landing to Goshen. Similar pebbles are found along the Goshen and Sligo turnpike from Goshen eastward past Skylight, and south from this turnpike in the heads of north tributaries of Harrods Creek. About a mile east of Skylight, where a private road comes to the turnpike from the north, glacial pebbles up to 6 inches in diameter were found.[25] The pebbles are imbedded in a reddish brown clayey deposit that seems to be mainly derived as a residuary product from the underlying limestone, and only to a subordinate degree supplemented by glacial material. In some of the pebbly clay the color is a more pronounced red than in the outlying districts where it is entirely of residuary character.

The westernmost bowlders noted in Oldham County are on uplands 1½ miles south of Westport, on the north side of Dunbar Branch. One quartzite is fully 2 feet in longest diameter, and a red jasper conglomerate is about 10 inches in diameter. A still larger quartzite bowlder lies in the bed of Eighteen Mile Creek 2 miles east of Westport, and an unclassified siliceous bowlder 3 feet in diameter as well as a small granite were found in the same creek valley one fourth mile above Oldham store on the land of Mrs. Mollie Findlay.

A gravelly deposit, or pebbly concentrate, with a depth of 3 or 4 feet, was found on the bluff south of Westport on land of Mr. Gottbraith. The pebbles include several colors of quartzite, in sizes up to about 2 inches in diameter, and an unclassified grayish rock of glacial derivation, as well as numerous white quartz and rounded cherts that are probably from the formations outcropping in the Ohio drainage basin. The quartz and chert far outnumber the other pebbles. This may be a pre-Illinoian concentrate into which a slight amount of glacial material has been introduced, about as in the residuary clay. No deposits of typical till, or of typical glacial outwash were noted in Oldham County, aside from the late glacial gravel in the Ohio bottoms, discussed below.

The border of the drift pebbles bears northward from the Goshen-Sligo turnpike near the place where the Westport road

[25]The roads and drainage referred to are represented on the Prospect topographic map.

comes in and follows the south side of Eighteen Mile Creek past Oldham store. It then seems to cross over the uplands north of the creek and enter Trimble County within 2 or 3 miles east of the Ohio River. On the ridge between Patton's Creek and Middle Creek in southern Trimble County it may be still nearer the river, but in Middle Creek valley drift pebbles were found fully 3 miles from the Ohio, and they occur to about that distance east on the ridge north of Middle Creek. A quartzite bowlder as well as numerous glacial pebbles were found on elevated upland north of Middle Creek 2 miles west of the Bedford-Lagrange turnpike. But none were found between there and Bedford. The entire drainage area of Bare Bone Creek, which heads at Bedford and leads southwest to the Ohio, seems to have been covered by the Illinoian icesheet. Patches of typical till are found on the uplands directly north of this creek, and within a mile north of Bedford. Along the creek and its main tributaries small bowlders are not rare, and they embrace several classes of rocks. A granite bowlder is imbedded at the base of a tree near the southwest corner of the court house square, but the writer was unable to learn whether it had been brought there by man. This village seems likely to have its location practically on the Illinoian drift border.

Illinoian till is present as far east as the highway leading from Bedford to Milton, Kentucky (opposite Madison, Indiana), and may extend a mile or two farther east. The thickest deposit noted along this highway is 10 or 12 feet. It is of clayey character, but thickly set with small pebbles. Limestone pebbles are common in the deeper part, but have been leached out of the upper part to a depth of 6 or 8 feet. Granite, greenstones, quartzite and quartz and chert pebbles, are present at all depths. There are very few pebbles over 3 inches in diameter, and no bowlders were seen within the till in Trimble County. They are, however, found in ravines and on hillsides, where till is not present. A bowlder of red jasper conglomerate 4 feet in diameter was removed from a woodlot just west of Vail to a farmhouse near the Carmel School, 3 miles north, which serves to illustrate how stones which have some attractive feature may now be far from the place where the icesheet left them.

Pebbles of glacial derivation were found at only one place within the drainage basin of Little Kentucky River, in Dry Fork of Hardy's Creek about a mile south of Vail, and 3 miles northeast of Bedford. Between there and the Ohio River the limits of the drift seem to be along or near the east bluff of Locust Creek. No glacial pebbles were noted east of Winona, nor along the road which follows the divide between Locust and Notch Lick Creek. Nor were any found along Notch Lick Creek and the divide between it and Little Kentucky River, nor along Little Kentucky River. There seems to be a small section of the south bluff of the Ohio, from Locust Creek to the mouth of Kentucky River that was outside the limits of the Illinoian icesheet. There is also an area of several square miles on the Indiana side of the Ohio between Madison and the valley of Indian-Kentuck Creek where only scattered bowlders and pebbles appear to be present, conditions being about the same as to the east of the Bedford-Milton highway. But a sheet of till covers the uplands on that side directly west of Madison, and also to the north of that city. Till is also abundant on the east side of Indian-Kentuck Creek clear down to the Ohio valley, a deposit 75 feet thick being present in a recess of the creek valley about a mile from the border of the Ohio Valley.

There is a heavy deposit of Illinoian drift on the south side of the Ohio directly above the mouth of the Kentucky, filling in a gap in the south bluff of the river. It has a relief of 40 to 60 feet above the adjacent bottom lands both of the Ohio and Kentucky, as aggraded in the Wisconsin stage of glaciation. At the west end the till appears on the slope of rock hills up to 125 feet above the bottom lands, or 200 feet above the Ohio at low water. So far as exposed the deposit is of clayey till, and contains numerous striated stones. Most of the stones are small, and very few reach a diameter of 6 inches. They embrace rocks of various kinds, but quartzite seems to be the most abundant in the leached surface portion.

From the east end of this drift ridge there is a rise of over 200 feet to the lowest deposits, found in the beds of small abandoned valleys, and 300 feet or more to the high uplands. In these valleys many small quartz pebbles are present in a sandy matrix, and these seem likely to antedate the Illinoian

stage of glaciation. There are, however, a few pebbles of glacial derivation which seem to have been incorporated in the older deposit at the Illinoian stage. The uplands seem to have only scattered pebbles and bowlders, no deposits of till having been noted. This condition is found eastward across Carroll and Gallatin Counties. Till, however, was noted on the brow of the bluff south of Warsaw. The scattered pebbles and occasional small bowlders are found on the uplands and slopes a little farther south than the divide between the Ohio River and Eagle Creek as far east as Glencoe, and the abandoned valleys standing 200 feet or more above the Ohio carry sandy deposits with numerous quartz pebbles, and an occasional glacial pebble or bowlder. The bowlders are usually of quartzite, and a few red jasper conglomerates were noted. The smaller stones include many greenstones and granites as well as quartzites.

From Glencoe the border appears to follow the east side of Sugar Creek valley northward to the Ohio Valley; at least no signs of glacial pebbles were seen along the highway from Glencoe to Napoleon, which follows the ridge east of Sugar Creek. Boulders and small erratics are numerous along this creek clear to its headwaters. From the mouth of Sugar Creek there is an abandoned valley leading northeastward to Big Bone Creek, that stands fully 200 feet above the Ohio, and which carries a few glacial pebbles in addition to numerous quartz pebbles and sandy material of the old valley floor. It is probable that this valley stands near the border of the Illinoian drift for no erratics were noted east of it. This valley continues northeastward into Boone County past Mud Lick Creek to the east fork of Big Bone Creek about a mile east of Big Bone Lick, and there turns westward and returns to the Ohio. All along its course and along the drainage lines between it and the Ohio Valley glacial pebbles are present, but there are very few on the bordering uplands. The drift pebbles are few and till seems not to be present in the district lying between Big Bone Lick and the village of Union. But both east and west of Union, till is well displayed, and it is found throughout the drainage area of Gunpowder Creek, and northwestward from there to the Ohio Valley. It is in this district that the Illinoian drift has its

farthest extent into Kentucky, as may be seen by reference to the glacial map, Plate 3.

There are places along the borders of the Ohio Valley, both in Indiana and Kentucky, where the drift presents a knolly surface. Near Bellevue, in western Boone County, Kentucky, the knolls occur up to a height of 250 to 300 feet above the river. But near there they are only 50 feet above the valley bottoms, or 150 feet above low water of the river. The knolls are composed largely of stony drift, in which the local rock formations are represented by large blocks of limestone. A few bowlders and smaller stones of glacial derivation are present. The material is but little waterworn or assorted by water action.

In western Boone County there are also masses of glacial conglomerate, of which "Split Rock" is the most widely known. This is a detached mass lying in the river on the Kentucky side. The conglomerate from which it is broken extends up to a height of nearly 100 feet above the river, and for a distance of an eighth mile or more along the bank. It extends for more than a mile along the east bluff, mainly below the mouth of Wolper Creek. It was noted by John Locke in an article in the Cincinnati Gazette in 1845, and Dr. George Sutton presented a paper on it, and neighboring conglomerates at a higher level before the American Association for the Advancement of Science in 1876, which appears in the Proceedings, and was reprinted in the Tenth Annual Report of the Indiana Geological Survey. Back of the Split Rock conglomerate, at about 300 feet above the Ohio, is another conglomerate, known as the "Middle Creek Conglomerate." From the wide difference of level at which these conglomerates occur, Sutton drew the inference that they are widely different in age, it being assumed that they are remnants of river terraces. They appear, however, to be better classed as exceptionally stony till, rather than an assorted stream deposit. The wide difference in altitude may thus signify nothing as to time relations. In fact deposits that are better assorted occur back of the Middle Creek conglomerate at higher levels. They occur along the road leading south into Middle Creek valley up to a level nearly 400 feet above the Ohio. One there finds exposed: First, silt, 5 feet, at top of bluff; second, gray sand, free from pebbles near top, but becoming peb-

bly and changing to brown color below, and grading into a coarse gravel and cobble, the whole formation having a thickness of 50 feet. The Middle Creek conglomerate sets in at a level about 50 feet below the base of this deposit and has a thickness of about 100 feet. There are large masses of detached conglomerate, and that which remains in place is deeply fissured, and presents a very uneven surface. This conglomerate is present at intervals for 3 or 4 miles north from the exposures on the Middle Creek road, and it occurs also to the south of the road. The conglomerates, both Split Rock and Middle Creek, consist mainly of loosely cemented stones, many of which are angular limestones. A few crystalline rocks of glacial derivation and a few quartz and chert pebbles were noted. These conglomerates and the knolls along the border of the Ohio Valley in this vicinity are probably a result of the bridging of the Ohio Valley by the icesheet, but just how they were produced is a matter for speculation and variety of opinion.

The border of the Illinoian drift passes from Boone into Kenton County about a mile northeast of Richwood and then follows down the valley of Bank Lick Creek to the Licking Valley in the south part of Covington. There are exposures of till in nearly every cut along the Southern Railroad from this border northward past Erlanger, but it is seldom more than 8 or 10 feet thick, and in some cuts is less than 5 feet. In its best exposures limestone pebbles as well as crystalline rocks are found, but they are all small, seldom over 3 inches in diameter. No boulders were found imbedded in the till, but boulders are present in the ravines that lead down to Bank Lick Creek. There are thin deposits of Illinoian till along the Lexington road from Erlanger northeast to Fort Mitchell. Between Fort Mitchell and Covington, as already noted, there is a very much weathered drift that seems likely to be pre-Illinoian. No place was found, however, where it is overlain by Illinoian drift. Some of the best exposures of Illinoian till in Kenton County are found in the heads of eastern tributaries of Dry Creek from Crescent Springs northwest to the Ohio bluff. They show numerous limestone pebbles as well as crystalline rocks, and the general aspect is much fresher than that of the deeply weathered drift back of Covington.

There was a more pronounced reentrant in the limits of the Illinoian icesheet at the Licking valley than at the mouth of the Kentucky. There is scarcely any drift on the narrow strip of upland between the Ohio and Licking valleys, or in any of the ravines tributary to these valleys, until one reaches the valley of Four Mile Creek at Silver Grove. But till is present on the Ohio side of the river, both on uplands and in ravines, in Cincinnati and eastward to and beyond the Little Miami Valley. Exposures of blue till as well as oxidized till are found in the valley of a small tributary of the Ohio entering at Columbia, Ohio, about a mile above its mouth, just north of the intersection of Linwood and Delta avenues, at an altitude about 600 feet A. T. To the north from there up to the ridge on which the observatory stands exposures of till are frequent. There are exposures of till near the intersection of Grandin Avenue and Madison Road on Walnut Hills within one half mile of the Ohio bluff, and boulders are to be seen on the grounds along Grandin Avenue that overlook the Ohio River. There are also exposures of till near the University, on the east side of Mill Creek Valley, and at points between there and Walnut Hills. It thus appears certain that the Illinoian ice reached to the Ohio Valley, and made notable deposits, directly opposite the part of Kentucky where there is scarcely a trace of Illinoian drift.

But a few miles up the Ohio Valley, near Silver Grove, Kentucky, till sets in on the Kentucky side, and is present from there south to the northern end of Pendleton County. It is present on hills more than 400 feet above the Ohio, and at all altitudes down to the level of the river bottoms, and is probably present beneath these bottoms. The highest measured point of its occurrence is on the prominent hill, 880 feet A. T., in the southeast part of the East Cincinnati topographic map, a mile south of Ross, Kentucky. The river opposite there, as shown by the same map, is below 440 feet. The till is usually less than 10 feet thick, and is leached of most of its limestone pebbles, but in the southeast corner of Campbell County it is thick enough to have unoxidized blue till preserved. There are ex-

posures of at least 20 feet of blue till in the head of the southernmost ravine in Campbell County, tributary to the Ohio, beneath a similar amount of oxidized till, and it extends below the bed of this tributary. Bowlders up to 3 feet in diameter, of granite, greenstone, and quartzite, abound along the bed of this tributary.

About $1\frac{1}{2}$ miles from the south line of Campbell County, and one-half mile north of Mentor, Kentucky, there is a drift-filled gap in the rock bluff, with surface about 160 feet above the Ohio River. This marks the place where drainage, now a part of Twelve Mile Creek, entered the Ohio River. It carried the present headwaters of Twelve Mile Creek from as far down as a narrow place in the valley a mile northeast of Flag Spring store, which at that time was a drainage divide. The depth of filling is probably somewhat more than 160 feet, as the Ohio Valley seems to have been cut to its full depth in pre-Illinoian time, and this tributary is likely to have had a bed correspondingly low. It may thus extend 50 feet below the low water level of the Ohio, and be fully 200 feet in depth. The width of the gap in the rock bluff is not more than 1,000 feet. The exposed part of the filling is largely a conglomerate, which stands in bluffs 10 to 20 feet high along the valley of Twelve Mile Creek for a mile or more in the vicinity of Flag Spring store. In a southern tributary for about 2 miles south of this store the farm wells are reported to obtain water in gravel at 20 to 25 feet. A clayey till is exposed on the ridge between this valley and the Ohio directly northwest of Mentor. Its upper limit there seems to be at about 650 feet, or 50 feet above the filled valley just noted.

The extent of the drift in southeastern Campbell County is generally about 2 miles beyond the west bluff of the Ohio, but in the lower end of Twelve Mile Creek Valley it extends 4 miles, to the bend of the creek, where it changes from a northwest to an easterly course. Within one-half mile below this bend a granite bowlder 4 feet in diameter stands at the roadside.

There is a thick deposit of glacial conglomerate in the lower end of Twelve Mile Creek Valley, about 2 miles above its mouth, which when viewed from below has the appearance of a great

dam of drift 75 feet or more in height. The stream cuts around its south edge into the rock bluff in a narrow gorge, strikingly in contrast with the half-mile wide valley below. Along a northern tributary of Twelve Mile Creek, which comes in just below the drift dam, there is considerable clayey till exposed. This is in a trench cut in the abandoned section of the predecessor of the Ohio, which connected Twelve Mile Creek with Ten Mile Creek, as described above. This trench is about 100 feet lower than the old valley floor, remnants of which appear along its sides, and between it and Ten Mile Creek. The drainage from its north end has been diverted westward into Four Mile Creek, probably as a result of the Illinoian ice invasion, for Four Mile Creek valley was less encroached upon by the ice sheet than the lower course of Twelve Mile Creek.

The Illinoian ice sheet seems to have barely reached the Kentucky bluff of the Ohio in northern Pendleton County in the vicinity of Ivor. There are drift deposits on the narrow ridge back of Ivor, between the Ohio and a south flowing tributary that enters at Carntown, Kentucky. A granite bowlder 4 by 5 feet in diameter was found in the bed of this tributary just south of the Campbell-Pendleton County line.

Glacial deposits of Illinoian age are found in at least two places along the south side of the Ohio in Bracken County, one being just west of Bradford, and the other about a mile east of Augusta. In both places they are very stony like a conglomerate, and made up largely of local limestones. But granite and other pebbles of glacial derivation are present. The deposit east of Augusta stands as a barrier across the lower end of Big Bracken Valley, and reaches a height of 150 to 175 feet above the Ohio River. The stream makes a great loop around it to enter the Ohio. The deposit near Bradford stands in relief above a narrow passage south of it, utilized by a highway.

Conditions for Illinoian Glacial Drainage in Kentucky

Although the Ohio valley and its tributaries seem to have been opened to their full depth prior to the Illinoian ice invasion, the icesheet covered the Ohio at its culmination to such a degree that there could not have been free drainage down that valley, in the part above Louisville, even if altitude relations

were favorable. The conglomerates of Illinoian age found at a few places along the Ohio valley do not seem to be referable to glacial drainage, but rather to local conditions of partial assorting where the icesheet was bridging the valley.

In the part of the Ohio valley below Louisville there is remarkably little material that seems referable to Illinoian drainage. Possiby a clay deposit near Bartles, Kentucky, standing about 475 feet A. T. is Illinoian. In the lower end of Blue River valley, near Leavenworth, Indiana, a terrace standing about 175 feet above the Ohio was found to carry a deposit in which a few pebbles of glacial derivation are present. They are higher than the Wisconsin glacial gravel reaches in that part of the valley, and also are more deeply weathered than is common in pebbles of Wisconsin age. They may prove to belong with pebbles found on the knobs in Meade County, whose relation to the Illinoian glaciation is still undetermined. In view of the general absence of pebbly material at this level along this part of the Ohio it seems questionable if the Illinoian valley trains were built up to such a height. Probably the Illinoian outwash deposits lie at similar altitude to the Wisconsin along the Ohio valley below Louisville. This suggestion seems pertinent since the Illinoian till in Jeffersonville, Indiana, across the river from Louisville, comes down about to the level of the valley gravel in the Ohio bottoms. Neither there, nor back from the Illinoian drift border, does there appear to be outwash of gravelly character, such as to give warrant for assuming vigorous drainage conditions, with an aggradation to a level 175 feet above the Ohio. The character of the drift border here, and also at other points where there seem to have been open valleys leading away from the border of the icesheet is such as to indicate poor drainage conditions. That the western part of the Illinoian icesheet in southeastern Iowa stood high enough for vigorous border drainage is shown in the large channel of the displaced Mississippi across that part of Iowa.[26] This channel is nowhere above 700 feet A. T. and is below 600 feet at Keokuk, where the stream made a conspicuous boulder deposit in the Mississippi valley. But from Keokuk, Iowa, around to Louisville, Kentucky, evidence of vigorous drainage is lacking. In the part of Kentucky

[26]See U. S. Geol. Survey, Monograph XXXVIII, pls. VI and VII, 1899.

to the east of Louisville there seems to be no line of displaced Ohio drainage along or near the border of the Illinoian drift such as that of the displaced Mississippi in Iowa. This may be due to other conditions than low altitude of the land with resultant imperfection of drainage. But it seems highly probable from the data at hand that drainage conditions were less favorable than they would be under present altitude relations in that region.

Pleistocene clay of considerable depth covers the lowlands between the Ohio and Green rivers in Daviess and McLean counties, and extends southward beyond Green River into the lower part of Pond River drainage. It is probable that a considerable part of this was deposited as early as the Illinoian stage of glaciation, but the greater part of the lowlands seems to have been flooded as late as the Wisconsin stage. Water at that time seems to have reached a level of fully 400 feet A. T. in the lowland as far down as the mouth of Green River. Shaw has called attention to this flooding, and given the name Green Lake to the water body that covered the lowland, the term lake being applied because of weak shore features formed on its borders.[27] These are best displayed in northern Muhlenberg County. The general poor development of shore features is attributed by Shaw to the rise and fall of the rivers that flooded the lowland. Thus the water's edge did not stand in one position long enough to develop shore features.

On the immediate border of the Ohio River there seems to be coarser material than on Green River and its tributaries, the records of borings in the vicinity of Owensboro being such as to indicate rather strong current from the top to the bottom of the filling. The logs mention "water sand, gravel and sand, good gravel, etc.," in alternating beds down to the rock which is struck at about 280 feet A. T. The filling is 110 to 120 feet in that vicinity. It probably is less toward the south border of the lowland, in the Green River drainage. But an average depth of 75 to 100 feet seems likely to be found throughout this extensive lowland. Its extent may be seen by reference to the topographic maps of the Owensboro, Newburg, Sefree, Calhoun,

[27]E. W. Shaw. Quaternary lakes in the Mississippi Basin; Jour. Geol. Vol. XIX, 1911, pp. 481-491.

Sutherland, Madisonville, Central City, Hartford, Nortonville, Drakesboro, and Dunmoor quadrangles, the areas below the 420 foot contour having been covered. A similar extensive lowland is found in the vicinity of the junction of the Wabash with the Ohio as may be seen by reference to the Henderson, Uniontown, New Haven, Shawneetown, Morganfield, Providence, and Earlington quadrangles, the areas below the 400 foot contour having been covered. Considerably more than 1,000 square miles fall within these two lowland areas, and the average thickness of the Pleistocene filling in them is likely to be not far below 100 feet. The amount of sediment thus seems to be about 20 cubic miles. While this deposition probably began as far back as the Illinoian stage of glaciation, there seems to be at present no means of determining how much of it is referable to the drainage from the Illinoian icesheet.

The following records of test borings in a survey for a bridge across the Ohio near Evansville, Indiana, 3 miles below the mouth of Green River, were obtained at the office of the City Engineer. As in the borings near Owensboro, the coarseness of the material indicates that strong river currents operated clear to the base of the deposit. Borings in the north part of Evansville are largely through blue clay to a depth of 80 feet. They are outside the range of the strong river currents.

TEST BORINGS ON OHIO RIVER 3 MILES BELOW MOUTH OF GREEN RIVER

Test boring on Indiana Bank, at 361 feet A. T.

Alluvium, sand, and river drift,	43 feet
Gravel with thin sand beds,	54 feet
Coarse sand,	10 feet
Gravel,	12 feet
Total, to sandstone floor,	119 feet

Altitude of rock floor 242 feet A. T.

Test Boring on Island in Ohio River.

Alluvium, sand, and river drift,	58 feet
Gravel,	37 feet
Coarse sand,	8 feet
Coarse gravel,	10 feet
Cemented gravel,	4 feet
Total to sandstone floor,	118 feet

Altitude of rock floor 243 feet A. T.
Distance from previous boring 1200 feet.

Test Boring on Kentucky Bank.

Alluvium, sand, and river drift,	33 feet
Coarse gravel, and small boulders,	53 feet
"Soapstone shale,"	10 feet
Coarse sand and gravel,	9 feet
Cemented gravel,	1 foot
"Shale"	1 foot
Total to sandstone floor,	107 feet

Altitude of rock floor, 254 feet A. T.
Distance from first boring, 2750 feet.

The above data were obtained by the writer in 1896. It is of interest to note that the map of the Henderson quadrangle, surveyed in 1914, shows no island in the river at this place. The entire low water flow of the Ohio is now south of Green River Island. In the absence of samples the writer can scarcely venture an opinion as to the deposit labeled "Soapstone shale" penetrated in the third boring. As it overlies sand and gravel it probably is a river sediment. The boring is nearly a mile distant from the rock bluff on the Kentucky side.

LOESS AND WIND DEPOSITED MATERIAL

The Jackson Purchase in western Kentucky is covered with a heavy deposit of typical loess, eastward from the Mississippi River bluff. Loess also covers a wide area in the Western Coal Field in Kentucky, and in southwestern Indiana, to a depth nearly as great as on the border of the Mississippi valley. It blankets the entire surface in the immediate vicinity of the Ohio to such a degree that many of the small streams have not cut through it and their beds are free from pebbles. A considerable part of Union and Henderson counties are thus blanketed with this deposit. The average thickness is probably not less than 20 feet. It is of porous character and of high agricultural value.

From Green River eastward there is but little typical loess but a silt or silt loam of slight depth is found where the slopes are gentle enough to retain it. The thickness seldom exceeds 6 feet. There are a few places along the east bluff of the Ohio both above and below Louisville where loess containing the typical molluscan fossils is present. This loess is somewhat coarser than the porous loess of western Kentucky. It has been used to some extent in foundries as a molding sand. The material in some of the dunes is but little coarser than loess. In some

cases the dunes in the vicinity of Louisville have a few feet of loamy material at surface but a nucleus of sand.

In the district in which Illinoian till is present there is a thin coating of silt over the till, in Kentucky as well as neighboring parts of Indiana and Ohio. It seldom reaches a depth of 6 feet and is a rather compact clay. It seems however to be a wind deposit. The underlying till developed a soil before the silt was laid down. An open cistern excavation at a residence on the Lexington pike two miles east of Erlanger offered an opportunity to see such a soil in 1924. The till is only 6 feet thick there, and is thoroughly leached of its lime content. The upper part for a depth of 2 feet has a deep brown color and carries a large amount of iron of brownish black color which ramifies it as if developed in root cavities. The color is darker and iron concentration much more marked than lower down and also than in the overlying pebbleless clay, that being of yellowish-brown color, and about 6 feet thick. In a trip some years earlier through that district a roadside ditch had been opened that exposed a black humus soil at the junction of the silt and till. This has the horizon of the Sangamon soil of States farther west and the silt thus has the age of the loess that overlies that soil.

There are thin deposits of silt over a considerable part of the Blue Grass region which seem to have been deposited by the agency of wind rather than of water. The thickness is only 2 to 4 feet and the deposit is patchy as well as thin, being present only where the slopes are very gentle.

In the Eastern Coal Field the slopes are generally too steep to permit the retention of deposits laid down by the wind. It is only in the old fluvial plains or in places with exceptionally gentle slope that material of this sort is likely to be preserved. The upper part of the silt deposit that fills these old valleys may prove to be a wind deposit, but the main body of the deposit is evidently waterlaid.

Glacial Drainage on Ohio River in the Wisconsin Stage

The Ohio valley was an outlet for several lines of glacial drainage in the Wisconsin stage of glaciation. The material brought in by these streams was transported down the Ohio far beyond the mouths of tributaries that contributed it, and the

valley bottoms appear to have been built up to a considerable amount at that time along the entire course of the river. The filling however seems to have been somewhat irregular, so that it reached greater height at and below the mouths of tributaries than in the part immediately above.

The filling at the place where the Ohio comes to the Kentucky boundary, at the mouth of Big Sandy River is shown by the Ceredo topographic map to be barely up to the 600-foot contour, or 114 feet above low water in the Ohio. In the Ironton sheet none of the bottom is up to 600 feet and very little above 580 feet. But below there at the mouth of the Scioto, as shown by the Greenup sheet, a small area in northeast part of Portsmouth catches the 600 contour. In the Vanceburg sheet on an inner curve of the stream opposite Vanceburg a sand terrace catches the 600 contour and dunes the 620 foot. There is also a filling to 600 feet back of Rome, Ohio, in the mouth of Stout Run. There seems to have been filling to nearly 600 feet as far down as Sand Hill station below Manchester. At this place, however, there is some complication for sand is present on the east bluff of the Ohio up to 800 feet, and it is difficult to fix the precise limits of stream action at the Wisconsin stage. Below Sand Hill the bottoms are mainly below 560 feet. They are mainly below 540 in the Higginsville sheet, and below 520 in the Felicity sheet.

Contributions of material from the Little Miami have built the valley up to 540 feet, and so have contributions from Mill Creek valley on which the city of Cincinnati stands. The filling on Mill Creek is above 560 feet at the Wisconsin drift border by Hartsville about 10 miles from the Ohio. The filling on the Great Miami at the Wisconsin drift border in the north part of the Lawrenceburg quadrangle reaches 585 feet, but it drops to about 520 feet at the edge of the Ohio valley near Lawrenceburg.

Below there topographic maps are wanting as far as the Prospect quadrangle. South of Prospect, Kentucky, there is a loess-capped terrace which catches the 500-foot contour, but this seems likely to be of pre-Wisconsin age. The valley bottoms below there standing 460 to 480 feet are not loess covered, and it is probable the upper limit of Wisconsin filling is about 480 feet. The Wisconsin filling in the east part of Jeffersonville,

Fig. 11. Map of northeast part of Kosmosdale quadrangle on which a dashed line has been added to show the position of the southeast bank of the Ohio in the Wisconsin stage of glaciation, on the top of which are sandy strips catching the 500 contour, deposited as a natural levee between the strong current of the Ohio and back water that was submerging to slight depth the "Wetwoods district" to the southeast of the levee. It is a definite bank 15 to 30 feet high, the base being below the 460 contour.

Indiana, is above 460 feet. The broad bottoms of the Ohio in the city of Louisville and for several miles southwest have sandy strips that catch the 460 contour. Sandy strips in the southeast part of the city have the appearance of a natural levee where the stream was passing the Wetwoods district, and this catches the 480 contour. (See Fig. 11.) In places the sand is built up to 500 feet, probably by wind action. There seems also to have been some heaping of sand by wind action in the broad bottoms southwest of Louisville. In the Wetwoods there probably was back water from the Ohio at the Wisconsin stage about to the 480 contour. The plain in Pond Creek valley where it enters the Ohio valley is coated with sand to a level slightly above 480 feet, while the dunes there are 500 to 520 feet. It thus appears that the waters in this glacial stage in and around Louisville were about up to the 480-foot contour.

The Artillery Range maps of the Camp Henry Knox district below Louisville show a broad bottom south of Pilchers with a level of 142 to 144 meters in the definitely graded eastern part, or 465 to 472 feet. A strip of dunes rises in one place to 161.2 meters, or 529 feet, and is largely above the 150 meter contour (492 feet). (See Fig. 12.) A clay deposit east of the dunes, standing about 475 feet above sea level, may be Illinoian. This is inferred from its being slightly above the general level of the Wisconsin filling, and also from the deep oxidation which it displays. This oxidation extends to a depth of more than 30 feet.

Topographic maps are wanting below there to the Tell City quadrangle. Gravel is present near Petri, Kentucky, up to about 420 feet that appears to be of Wisconsin age and the water level was perhaps 10 feet higher. This drop of 45 feet from the district last noted is made in a distance of about 90 miles by the windings of the stream.

In the Owensboro and Sutherland quadrangles ridges of fine sand which catch the 420-foot contour (See Fig. 13), seem to have been formed at the border of the strong current as natural levees while the low districts to the south were flooded with back water. This back water covered wide areas as noted in the discussion of the Illinoian drainage, and appears to have been a feature of both the Illinoian and Wisconsin stages. The sandy

FLUVIO-GLACIAL FEATURES AND DUNES OF OHIO RIVER BOTTOM.

Fig. 12. Contour map of east part of Ohio River valley south of Pilchers, Meade County, Kentucky. Dunes are here prominent on a terrace of the Illinoian glacial stage, the part of the valley bottom above the 145 meter contour being sandy. The water deposited material has an upper limit at about 142 meters, or 466 feet A. T. The contours are from Artillery Range Sheet 1, Camp Henry Knox, Kentucky.

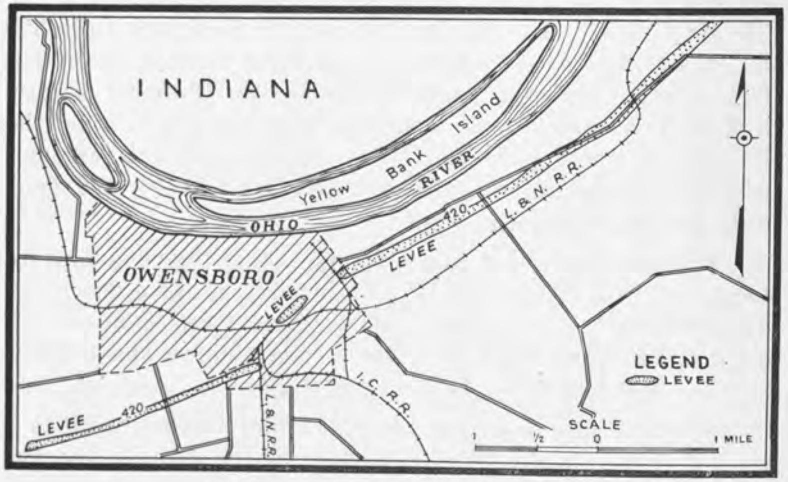
levee just noted is likely to be as recent as the Wisconsin stage. The Ohio was probably flooded in this later stage to fully 400 feet as far down as the low country around the mouth of the Wabash. There may have been considerable descent between there and the mouth, in the passage through the ridged area known as the "Ozark Uplift." But the level is likely to have been fully 350 feet at the mouth. The present high water there is about 320 feet. The broad Cache Valley connecting the Ohio and Mississippi in Pope and Massac counties, Illinois, as shown by the Brownfield topographic map is between 340 and 360 feet, and probably represents about the height reached by the flood waters in the Wisconsin stage.

It thus appears that in the 650 miles that the Ohio flows on the border of Kentucky the Wisconsin filling shows a descent of about 250 feet. The stream at low water shows a descent of about 220 feet, low water at Ashland being 486 feet and at Cairo 267 feet above sea level, as given by Gannet.[28]

While it is evident that the Ohio valley was aggraded to a marked degree in the Wisconsin stage by the deposits brought in from the icesheet it is not certain that these deposits extend to the lowest levels of the rock floor, but they seem to extend down to rock shelves that are about at low water level of the river. The rock floor seems to have been cut generally to a depth of about 50 feet below low water, and in places 75 to 100 feet. At the places where the river has been thrown across cols near Cincinnati the rock floor is perhaps less than 50 feet for a short section of the stream bed. There are a number of places where the stream is now cutting into rock on the borders of the valley and avoiding the deeply cut channel which it had opened prior to the Wisconsin filling. At such places there is usually only a slight descent making merely a riffle, but at Louisville there is a descent of about 20 feet in the space of a mile, and this is known as the Louisville Falls. A buried channel at least 40 feet below the level at the head of the falls has been traced through the city of Louisville. There may also be a channel of similar depth passing under Jeffersonville, Indiana, to Silver Creek valley, on the north side of the falls, as suggested by Sieben-

[28]Bull. U. S. Geol. Survey, No. 274. The Ceredo topographic map shows the 500-foot contour to extend only to the mouth of the Big Sandy, but that is not low water level.

thal.[29] The data given by Siebenthal are inconclusive for the reason that one of the well records, (well No. 7) at a critical point, where one would expect the channel to be deepest, struck rock at only 40 feet, or about at low water level of the river. A



LEVEE IN WESTERN KENTUCKY

Fig. 13. Map showing natural levee of Ohio River near Owensboro, Kentucky. It embraces the shaded area above 420-foot contour.

well at Utica, Indiana, reported by Siebenthal, went to a level 80 feet below low water or to about 325 feet A. T. entirely in gravel, and a well at Mechanic and Chestnut streets in Jeffersonville went 40 feet below the level of the reef at the falls before entering rock. Both these wells fall within the natural limits of a channel passing south of the falls.

There seems to be a general descent in the rock floor along the Ohio from the mouth of the Great Miami down to Louisville, though the river may have scoured at certain places to exceptional depth. Thus a boring recently made in the valley four miles below Madison, Indiana, is reported by Prof. Glenn Culbertson to have been sunk to a depth of 172 feet, or a level about 110 feet below the river at low water, entirely in river deposits of gravel and sand.[30] The rock floor is thus much lower than yet found at any point above and fully as low as at any place thus

[29] C. E. Siebenthal: 25th Report Ind. Geol. Survey, 1901, pp. 363-364.
[30] Personal communication.

far discovered within 50 miles below Madison, being not over 300 feet A. T.

The greater part of the valley filling seems to be of sand and gravel, as indicated by numerous borings well distributed along the valley. But there are only a few places where the gravel is found at the surface. The upper 15 to 25 feet is ordinarily of relatively fine material. In some places it is of a texture suitable for molding sand, as at Mentor and at Brent in Campbell County. More often the sand is of irregular grades of coarseness, and more or less pebbly. There are also sections of considerable length where the material is of clayey character and contains large as well as small stones. Such deposits however are probably due to a postglacial working over and redeposition of the material in flood stages. Deposits of this kind in places bear some resemblance to till, especially in the manner in which pebbles are mixed in with the clay, but the clay is clearly a water bedded material. It is probable that the stones were to some extent carried by ice cakes and dropped into the finer sediment wherever the ice chanced to lodge and melt.

On the lower Ohio the cherty polished gravel from the Lafayette deposits has been incorporated with the glacial material in the present valley. The gravel dredged from the Ohio River bed near Tell City, Indiana, is mainly of chert pebbles of the polished, bronzed type found on the bordering hills. All along the valley there has been a liberal admixture of material washed in from tributary gulches, but enough material of glacial derivation is present to give character to the deposits and justify their reference to glacio-fluvial action. It is because of the heavy burden of material contributed by the melting icesheet that the valley became aggraded to such a marked degree.

APPENDIX

Results of examinations of thin sections of the eastern Kentucky erratics.

By Walter F. Hunt and Floyd Poindexter
University of Michigan

These thin sections were prepared and mounted by W. L. Tomlinson of Swarthmore, Penn., with some supplementary ones by Poindexter from rock specimens supplied by W. R. Jillson.

No. 1 K. Sandstone, weight 8½ lbs., from left fork Newcomb Cr. 2½ mi. above Isonville, Elliott Co., altitude 754 feet.

A feldspathic sandstone, consisting for the most part of rounded grains of quartz with some orthoclase, microcline, plagioclase and microperthite. A few flakes of muscovite, considerable chlorite, and several crystals of zircon were identified in the section. The quartz contains rutile needles. In some portions of the section the quartz grains are interlocked, giving rise to a mosaic structure, so that possibly some induration has occurred. The grains are, however, for the most part separated by interstitial limonite and chlorite, and the structure is typically clastic.

No. 2 K. Quartzite (slightly schistose) from same locality as No. 1. Weight 4½ lbs.

A rock consisting almost entirely of quartz, some of the grains being large, others small, as a result of granulation. All of the quartz grains are interlocked in a mosaic, and many show shadowy or wavy extinction, indicating strain. There is considerable muscovite in the section, several grains of tourmaline and zircon are present. The quartz contains rutile needles, and limonite, hematite, and organic matter are also present.

No. 4 K. Sandstone from 1 mi. below Isonville, Elliott Co. Weight 1½ lbs.

A compact sandstone composed entirely of quartz with a limonite and quartz cement. In some cases there has been a new deposition of quartz in optical continuity with the original grains, the new material being separated from the old by a thin ring of limonite. The quartz contains inclusions of rutile, zircon, and biotite.

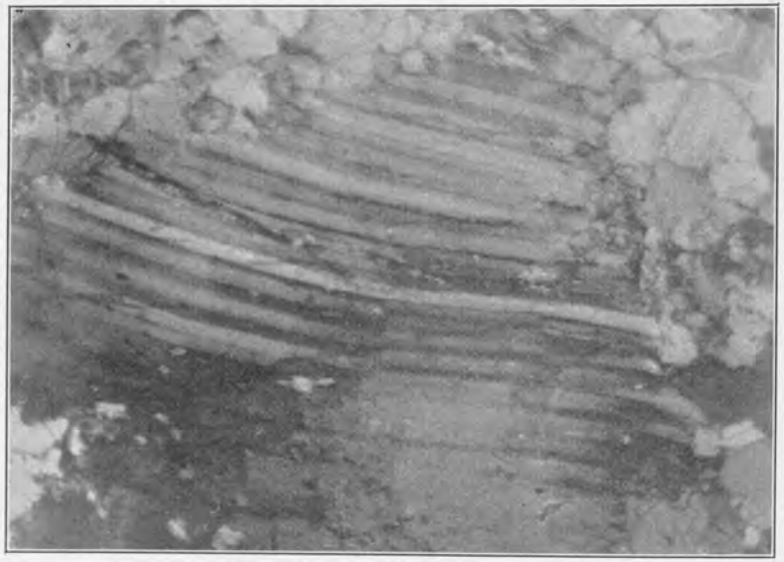


Fig. 14. Photo of thin section of norite gneiss, or hyphersthene gabbro, as seen under microscope with crossed nicols and magnified 80 times. The curved lines show effect of pressure on labradorite. Photo by Walter F. Hunt.

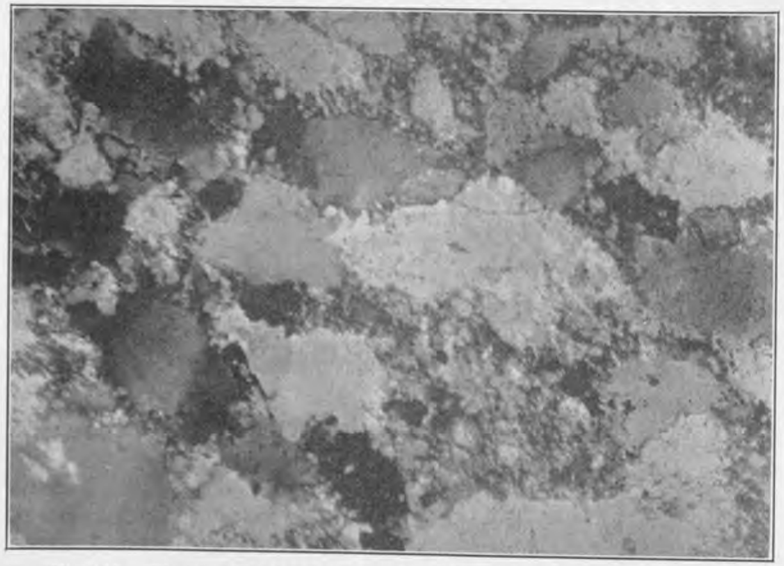


Fig. 15. Photo of thin section of schistose quartzite, from Farmers, Kentucky, as soon under microscope, magnified 80 times. It illustrates well the interlocking of grains, and the granulation, forming small grains surrounding larger ones. Photo by Walter F. Hunt.

MICRO-SECTIONS EASTERN KENTUCKY GLACIAL ERRATICS

No. 5 K. Norite gneiss from Lawrence County, Kentucky, 2 mi. N. of Glenwood, on E. Fork Little Sandy River. Altitude 792 feet. Weight 2¾ lbs.

A dark straw-colored crystalline pebble containing long crystals of a brownish black mineral, arranged in parallel fashion, giving rise to a gneissic structure. A few grains of pyrite are microscopically visible.

In thin section the rock is seen to consist of plagioclase feldspar (labradorite) and hypersthene as the essential consitutents. Accessory minerals are magnetite, hematite, limonite, and pyrite. It is probable that in addition to the hyperthene there are a few grains of bronzite, these having little or no pleochroism, and being optically positive. However, by far the greater amount of the pyroxene shows the intense pink and green pleochroism of hypersthene.

The plagioclase is some cases shows the effect of pressure (See Pl. 14A and B, several grains having bent and twisted lamellae, which extinguish between crossed nicols, in an undulatory manner, another indication of strain. The color of the rock is due to iron oxide, limonite stains being observed throught the section.

No. 11 K. Quartzite from Morgan Co., Ky. N. Fork Licking R. near Wrigley. Altitude 850 ft. Weight 6¾ lbs.

Megascopically the rock is a fine grained quartzite, stained slightly brownish. Microscopically it is composed essentially of quartz with rather irregular interlocking grains. Aside from quartz small amounts of the following minerals were seen in the section: Zircon, pyrite, hematite, tourmaline (one unusually large grain), microcline, apatite, biotite ann muscovite.

No. 12 K. Granodiorite from Wrigley, Morgan Co., Ky., on N. Fork Licking R. Altitude 800 feet, weight 4 oz.

Megascopically, an even-grained, medium-textured rock of whitish color, which in the field would unquestionably be called granite.

Microscopically, the feldspars are badly altered to sericite mica and kaolinite. One is impressed with the rather large amount of plagioclase (oligoclase) present; approximately as much plagioclase as orthoclase. Other minerals found include quartz, biotite altered to chlorite, apatite and zircon.

No. 13 K. Granite from Carter County, Ky., on Mill Br. of Tygart's Creek, above falls, near Cedar Branch School. Alt. 830 feet. Weight one lb.

A brownish pebble of feldspar and quartz, having an earthy odor, and showing signs of decomposition. With the exception of magnetite the dark constituents are apparently absent. The magnetite is abundant and is easily recognized with the hand lens.

In this section the rock has the characters of an igneous rock, and is composed entirely of feldspar (orthoclase and albite) and quartz, with a few accessories. There is also an intergrowth of the orthoclase and plagioclase. Limonite is plentiful, accounting for the color of the rock. There is also a little hematite, and considerable magnetite, as well as a number of large crystals of zircon. Very little of the feldspar is fresh, most of it being badly altered to kaolin.

No. 18 K. Binary granite from Wrigley, Ky., on N. Fork Licking R. Altitude 800 feet. Weight 2½ oz.

Megascopically, the rock is even-grained and medium-textured and consists of pink feldspar, quartz, and black mica.

Microscopically, abundant microcline is present, with characteristic cross-hatched twinning. Also orthoclase, quartz (some of it micrographic intergrowth with feldspar), biotite altered to chlorite, muscovite and plagioclase (basic oligoclase). As accessories both apatite and zircon were also observed.

16-Ton boulder on Knobstone Hill.

No. 19 K. Porphyritic granite-gneiss, from near Epworth, Lewis County, Ky. Altitude 986 ft.

A rather dark-colored gneissic rock, having large crystals of pink orthoclase in a coarsely crystalline groundmass of quartz, feldspar and mica.

The following minerals were identified under the microscope: Orthoclase and quartz, plagioclase (the few grains present in the section were not suitable for determining the character, however, it has a low index, and is no doubt albite or oligoclase), green biotite, muscovite, abundant apatite, zircon, hematite and limonite. Secondary minerals: Sericite, chlorite and calcite.

No. 20 K. Schistose quartzite from near Farmers, Rowan County, near Licking River.

The specimens were taken from a boulder located on the farm of Dr. H. Van Antwerp at an elevation of 720 feet. The boulder is oval in shape, well rounded, and is estimated to weigh about three tons. It is light gray in color, probably due to the graphitic material present, and on a fresh fracture shows a greasy luster and resembles a mica-schist.

Veinlets of clearer quartz cut through the rock, in some cases parallel to the planes of schistosity, in other cases cutting across them. The rock may have been subjected to considerable pressure in the zone of fracture, thus producing cracks which became filled with quartz deposited by the circulating waters. The microscope shows that these veinlets have also been subjected to metamorphic processes, hence it is not unlikely that the rock later passed into the zone of

anamorphism where the crushing and schistosity were produced. These veinlets contain pyrite and in some cases a thin layer of limonite along the walls.

The microscope shows the rock to be free from mica with the exception of a few flakes of muscovite. It is composed almost entirely of quartz grains, which have been granulated to form smaller grains surrounding the larger ones. This is the typical "mortar" structure. In some portions, especially in the veinlets of quartz, a "mosaic" structure is characteristic, the grains interlocking with one another. A few grains of orthoclase and plagioclase are present. Numerous well developed rhombohedrons of dolomite were obviously introduced subsequent to the metamorphic processes, or else they would be deformed. In some cases these crystals have been replaced by limonite. See photo of silde Pl. 14B.

Appendix II. Big Bone Lick, and Early Views as to Fossils Found There

Big Bone Lick, in western Boone County, Kentucky, seems to have been one of the earliest places in America to be explored for its fossil bones. Collections were made there at some time prior to 1784 for they were discussed that year in an essay by John Filson as shown in the quotation below. It is thought by Hay that of mastodon bones alone some tons have been collected at this place, but that nearly all of this important material has been lost. He also places the first collection of bones as far back as 1739. He states that General William Henry Harrison, in 1795, shipped from there 13 hogsheads of bones, but these were lost on their way to Pittsburg.

This salt lick is located in the lower end of Big Bone valley within two miles of the Ohio River, and at a level but little above present floods. The border of the Illinoian drift passes near this lick, but the deposits in which the bones are imbedded are likely to be largely of post Wisconsin age. The fossils are chiefly of species found elsewhere on the surface of the Wisconsin drift, and there seems to be nothing so far as the geological conditions have a bearing to suggest their burial in pre-Wisconsin time. But Hay cites certain species found here, as *Mylodon harlani* and *Equus complicatus*, which elsewhere seem not to have survived the Wisconsin glacial stage. He also regards the musk-ox *Symbos cavifrons* and *Bison antiquus* as pre-Wisconsin, both of which are represented here. The following is a list presented by Hay of

the species found at Big Bone Lick. The page references are to his discussions in the monograph.[1]

List of vertebrate species at Big Bone Lick.

Giant sloth. *Megalonyx jeffersonii* (p 44).
Sloth. *Mylodon harlani* (p. 44).
Horse. *Equus complicatus* (p. 202).
Tapir. *Tapirus haysii* (p. 209).
Virginia deer. *Odocoileus virginianus* (p. 234).
Elk. *Cervus canadensis* (p. 243).
Moose. *Cervalces scotti.*
Moose. *Alces americanus.*
Caribou. *Rangifer caribou* (p. 247).
Musk-ox. *Bootherium bombifrons* (p. 255).
Musk-ox. *Symbos cavifrons* (p. 255).
Buffalo. *Bison antiquus* (p. 265), and *B. bison* (p. 270).
Mastodon. *Mammut americanum* (p. 128).
Elephant. *Elephas primigenius* (p. 146), and *E. columbi* (p. 160).
Bear. *Ursus americanus.*

From an essay by John Filson, published in America in 1784, entitled "The discovery, settlement, and present state of Kentucky: and an essay towards the topography and natural history of that important country." This was reprinted in Imlay's "North America," published at London in 1793. See pp. 306-309 for this quotation:

"At a salt spring near Ohio River, very large bones are found, far surpsassing the size of any species of animal now in America. The head appears to have been about three feet long, the ribs seven, and the thigh bones about four; one of which is reposited in the library at Philadelphia, and said to weigh 78 pounds. The tusks are above a foot in length, the grinders about five inches square and eight inches long. These bones have equally excited the amazement of the ignorant, and attracted the attention of the philosopher. Specimens of them have been sent both to France and England, where they have been examined with the greatest diligence, and found upon comparison to be the remains of the same species of animals that produced those other fossil bones which have been discovered in Tartary, Chili, and several other places, both of the old and new continent. What animal this is, and by what means its ruins are found in regions so widely different, and where none exists at present, is a question of more difficult decision. The ignorant and superstitious Tartars attribute them tc a creature which they call Maimon, who, they say, usually resides at the bottom of the rivers, and of whom they relate many marvelous stories; but as this is an assertion totally divested of proof, and even of probability, it has justly been rejected by the learned; and on the other hand it is certain that no such amphibious animal exists in our American waters. The bones themselves bear a great resemblance to those of the elephant. There is no other terrestrial animal now known large enough to produce them. The tusks with which they are equally furnished, equally produce true ivory. These external resemblances have generally made superficial observers conclude that they could belong to no other than that prince of quadrupeds; and when they first drew attention of the world, philosophers seem to have subscribed to the same opinion. But if so, whence is it that the whole species has disappeared from America? An animal so laborious and so docile, that the industry of the Peruvians, which reduced to servitude and subjected to education species so vastly inferior in those qualities, as the Llama and the Paca, could ever have overlooked the elephant, if he had been to be found in their country. Whence is it that these bones are found in climates where the elephant, a native of the torrid zone, cannot even subsist in his wild state, and in a state of servitude will not propagate? These are difficulties sufficient to stagger credulity itself; and at length produced the enquiries of Dr. Hunter. That celebrated anatomist, having procured specimens from the Ohio, examined them with that accuracy for which he is so much distinguished. He discovered a considerable difference between the shape and structure of the bones and those of the elephant. He observed from the form of the teeth, that they must have belonged to a carnivorous animal; whereas the habits of the elephant are foreign to such sustenance, and his jaws totally unprovided with the teeth necessary for its use; and from the whole he concluded, to the satisfaction of naturalists, that these bones belonged to a quadruped now unknown, and whose race is probably extinct, unless it may be found in the extensive continent of New Holland, whose recesses have not yet been pervaded by the curiosity or avidity of cilivized man. Can then so great a link have perished from the chain of nature? Happy we that it has. How formidable an enemy to the human species, an animal as large as the elephant, the tyrant of the forests, perhaps the devourer of man. Nations, such as the Indians must have been in perpetual alarm. The animosities among the various tribes must have been suspended till the common enemy who threatened the very existence of all, should be extirpated. To this circumstance we are probably indebted for a fact, which is perhaps singular in its kind, the extinction of a whole race of animals from the system of nature."

[1] O. P. Hay: The Pleistocene of North America and its vertebrated animals, Carnegie Institution of Washington, Publication 322, 1923. P. 403.

References to the bones of the "Mammouth" at "Great Bone Lick" in Imlay's "North America." Published at London in 1793. Pages 47-48, and page 236.

"Between the mouths of the Licking and Kentucky lies the Great Bone Lick, which is justly celebrated for the remarkable bones which are found there, and which gave name to the place. Several of these bones have been sent to Europe; but I believe no person who has written upon natural history has given any decided opinion as to what class of animals they belonged. Buffon has called them the "Mammouth;" but I am at a loss to know from what authority, as we have no tradition either oral or written, that gives an account of any species of animals which were as large as those must have been, judging by the magnitude of the bones. Buffon says, that similar bones have been found both in Ireland (if I am not mistaken) and in some part of Asia. It appears somewhat extraordinary, at the first view, that we should discover manifest proofs of there having existed animals of which we can form no adequate idea, and which in size must have far exceeded anything now known upon earth; and those signs too, in climates where the elephant (the largest animal now in existence) is never found. Every phenomenon upon the earth tends to confirm the idea, that it ever has been subject to revolutions, besides its diurnal and annual motion from east to west." (Pp. 47-48.)

"I have already taken notice of the great bones which have been found in this country; but as I was not minute as to the estimate of their size I shall just remark, that it was the opinion of your celebrated anatomist, the late Dr. Hunter, from an examination of the tusks, that the mammouth was an animal entirely different from the elephant; and Mr. Jefferson, who seems to have examined the skeleton with curious attention, says, 'The bones bespeak an animal of five or six times the cubic volume of the elephant, as Mons. de Buffon has admitted.' And I have been informed by a gentleman who attended the lectures of Dr. Cline, in London, that this ingenious anatomist used to produce one of the tusks of the mammouth when lecturing, and declared that the animal must have been carnivorous." (P. 236.)

II.

The
CLIMATE OF KENTUCKY

By

STEPHEN SARGENT VISHER
Assistant Geographer
and Professor of Geography at the
University of Indiana

Illustrated with 109 Maps and Diagrams

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THE CLIMATE OF KENTUCKY

By Stephen S. Visher

INTRODUCTORY

The conditions of the atmosphere affect mankind in many ways, both directly and indirectly. The conditions of temperature, winds, atmospheric moisture, cloudiness, precipitation and air pressure, of any particular time, together make up what is called the weather. The weather is an almost universal topic of conversation because of its profound economic significance, and because of its numerous subtle effects upon our activities and feelings. A needed rain at a critical time may increase the yield of a crop sufficiently to be worth millions of dollars to the farmers, and hence to the nation, but the same rain may spoil numerous picnics, may damage another crop, roads or equipment. Or the lightning, and perchance the hail or violent wind, incident to a heavy rain may be quite destructive locally. The weather continually illustrates the natural law that in this world there is nothing wholly good nor wholly bad. "Every cloud has its silver lining." "Perfection is not of this world."

Climate is the average meteorological conditions prevailing at any place during any considerable period. In other words, it is the average of the past weather. Each of the elements of the weather may be averaged separately for any sort of period desired, provided the period is not too short. Thus climate includes such topics as the average temperature throughout the year, the mean temperature of any given season such as winter, the mean temperature during the hottest time of the day during the summer, the frequency, on the average, of temperatures above or below certain limits, for example 100° F. and 0° F. Climate even includes a description of the average and hence the expected condition of a particular date, such as July 4 or December 25, because the expected conditions are based on the average of available records for that date during the previous years.

The climate of no two places is exactly the same because one or another of the several influences making the climate what it is differs from place to place. Seven chief influences affecting climate are: (1) distance from the equator, which determines the height of the sun at any given time of the day, and the

length of day and night. These profoundly influence the effectiveness of solar heating and have led to the development of great wind belts. (2) The elevation above sea level influences air pressure and the average temperature, as these normally decrease at progressively higher levels. The decrease in temperature at higher elevations often leads to precipitation, because when air is cooled, its capacity for moisture is decreased, (being halved by a reduction of 18° F.) (3) A third great influence causing differences in climate is contrast in the relation of places to the ocean, the main source of moisture, and the great stabilizer of temperature and a great modifier of winds. (4) Relation to lakes and other bodies of water is also significant, as even a pond has some slight influence upon the climate of the adjacent areas, especially those to the leeward. The relation of places to the ocean or lakes is not so much a matter of actual distance as of effective distance. A mountain range between a place and a nearby ocean may have the same effect as a vastly greater remoteness from the ocean would have. Hence the relation of places to mountain ranges is a fifth great contrast. (6) Places differ also in their relation to the paths followed by cyclonic disturbances. These disturbances, called Lows and Highs on the Daily Weather Maps, produce most of the irregular changes of weather. Hence a place located so as to be influenced by many passing disturbances will have a different climate than a place not so located. (7) As ocean currents influence the climate of areas to the leeward, their location is also significant.

Other causes of contrasts in climate are contrasts in slope, relation to hills and valleys, differences in the color and wetness of the soil, and in the character of the vegetation, especially whether trees, coarse crops or grass dominate. Local differences are also produced by buildings, roads, fields and fires, including furnace fires, with their smoke.

Many people in any region are interested in the climate of their region, because a knowledge of what has happened in the past is the best basis for prediction as to the future. In other words, climate, the average of past weather, so far as recorded, is the best basis for the prediction of the weather of the future, except that future which is so near at hand that the character of the cyclonic disturbances already observed close at hand and moving towards the area form an even better basis for prediction.

Indeed it is by the study of approaching cyclonic disturbances that the daily forecasts are made by the U. S. Weather Bureau. But even these forecasts are profoundly modified by what the records of the past have shown as to the movements and changes of similar cyclonic disturbances which approached the area during the past. In order efficiently to use our soil and other resources, a full knowledge of the climate is essential. A better adjustment of crops to climate awaits a full knowledge of climate. Likewise, in order wisely to construct our roads, sewers, bridges and buildings, a knowledge is required of what may reasonably be expected in the matter of rainfall, ice, winds, and drought.

It is not enough that a few specialists have this necessary knowledge. Specialists are seldom consulted except by those who already have considerable knowledge about a subject. Indeed those who know least are least likely to seek expert knowledge and those who know most are most alert to learn more.

It is hoped by the Director of the Survey and the author of this bulletin that the following presentation of the climate of Kentucky will not only interest the citizens of Kentucky and give them knowledge which will prove valuable, but that it will stimulate them to seek fuller knowledge, and to encourage those who are gathering further knowledge. It is also hoped that persons outside of Kentucky who may chance to see this report will have increased interest not only in Kentucky and her resources but will appreciate increasingly her progressiveness. No other state has so complete a report upon its climate.

Acknowledgments

The United States Weather Bureau, a division of the U. S. Department of Agriculture, has for years gathered facts as to the weather and climate of the United States. It has had the cooperation of many private individuals, who have become voluntary "cooperative observers." At present there are nearly seventy such observers in Kentucky. The Weather Bureau has issued tables of the precipitation and temperature by months for the cooperative stations in Kentucky and fuller data for the regular stations (Louisville and Lexington). Persons wishing precise data concerning the individual stations, in addition to

the data given in tables 1-3, should consult the "Summary of the Climatological Data for Sections 75 and 76" covering Eastern and Western Kentucky from the establishment of the stations to the close of 1922. Later data may be found in the Annual Summaries, issued shortly after the close of each year for the state as a whole and for Louisville and Lexington. The leaflets issued by the regular weather bureau stations at Cincinnati, Ohio, Evansville, Indiana, and Cairo, Illinois, are significant for parts of Kentucky also, as these cities are just across the Ohio River.

As valuable as the tables of climatological data are, they are hard to read and interpret. Maps shaded to show variations are distinctly more serviceable in depicting the broader aspects of the climate. The following maps present many phases of the climate of Kentucky in a form which should prove both clear and useful.

These maps are based, necessarily, upon data gathered by the U. S. Weather Bureau. Although only a very few of them have been published before, many of them are based on the Kentucky portion of maps of the United States showing regional contrasts in respect to the subject of the map. In the present series, however, consideration is taken of additional Kentucky records.

The obligation of all persons interested in the climate of any portion of the United States to the painstaking and thoroughly admirable work of the members of the United States Weather Bureau is, obviously, very great. The present writer is under especial obligations to J. B. Kincer for his valuable maps, recently prepared for the forthcoming Atlas of American Agriculture, for these maps form the basis for a considerable number of the present series.

It is also a pleasure to acknowledge cooperation from the officials in charge of the regular Weather Bureau stations in and adjacent to Kentucky. Meteorologist J. L. Kendall of the Louisville station has been especially helpful, not only having supplied data, but having kindly read the manuscript and maps, and made helpful suggestions concerning them.

KENTUCKY CLIMATE

Kentucky (area 40,589 square miles, population about 2,500,000) is situated just south of the Ohio River, and extends from the Mississippi River to the Appalachian Mountains. Its general location is clearly shown in Figure 1. The states bordering are Tennessee, Virginia, West Virginia, Ohio, Indiana, Illinois, and Missouri. Their location in respect to Kentucky is shown on maps, 3 to 93. The center of state is about 37° 30′ north latitude and about 85° west longitude.

Most of the state is rather hilly, and the easternmost portion is mountainous. The relief is shown in Figure 2, a photograph of the relief map distributed by the State Geological Survey. The largest area which is fairly smooth is the famous "Blue Grass Region" in the northeast central part of the state. This section is especially rich agriculturally, producing much tobacco and corn. Agriculture is the chief occupation in all but a few counties. It is exceeded, however, by manufacturing in Jefferson County (Louisville) and by coal mining in several eastern and western counties. The value of crops grown in 1919 is re-

Fig. 1. Relief map of the United States (courtesy of the United States Geological Survey) showing the location of Kentucky.

Fig. 2. Relief Map of Kentucky.

ported as over 347 million dollars, and the value of manufactures in 1923 was 427 million dollars. However, a considerable share of the value of manufactures was the cost of raw materials. The value added by manufacturing in the state was less than the value of agricultural products. In 1924, 45 million tons of coal were mined, and 7.4 million barrels of petroleum were obtained from oil wells. Lumber valued at about 20 million dollars is cut annually.

Kentucky has a continental climate of the warm, humid type. This type of climate is favorable for corn and fairly favorable for winter wheat. Kentucky is near the center of "the corn and winter wheat belt," which belt is situated between "the corn belt" and the "cotton belt."

A continental type of climate is one possessed of marked contrast between winter and summer such as is found in middle latitudes within the continents. A humid climate is one having, in middle latitudes, an average annual precipitation of over twenty inches. Kentucky's average is over forty inches. Kentucky is situated in the warm, humid continental climate because the summers are long enough and warm enough for corn to thrive. The cool humid continental climate is north of the corn belt. The southwestern counties of Kentucky are warm enough for cotton to thrive therein.

Kentucky is about 380 miles ($7\frac{1}{2}°$) long, east and west, but has an average width (N-S) of only about 100 miles ($1\frac{1}{2}°$), and a maximum width of only about 170 miles. This small contrast in latitude means that the contrast in climate between southern and northern Kentucky is much less than is found in certain other states; for example, Indiana (extent, 4° in latitude), New York ($4\frac{1}{2}°$) and Illinois (5°). Nevertheless there are appreciable contrasts in temperatures and the length of the growing season between northern and southern Kentucky, and the effect of latitude is seen on many other maps. In east central North America, latitude is significant not only because of the angle at which the sun shines at noon, and the length of the day and night but because the great source of moisture is the Gulf of Mexico, at the south. There is a progressive decline in precipitation northward from the Gulf of Mexico, except where the rainfall is increased by mountains, as in the Appalachians.

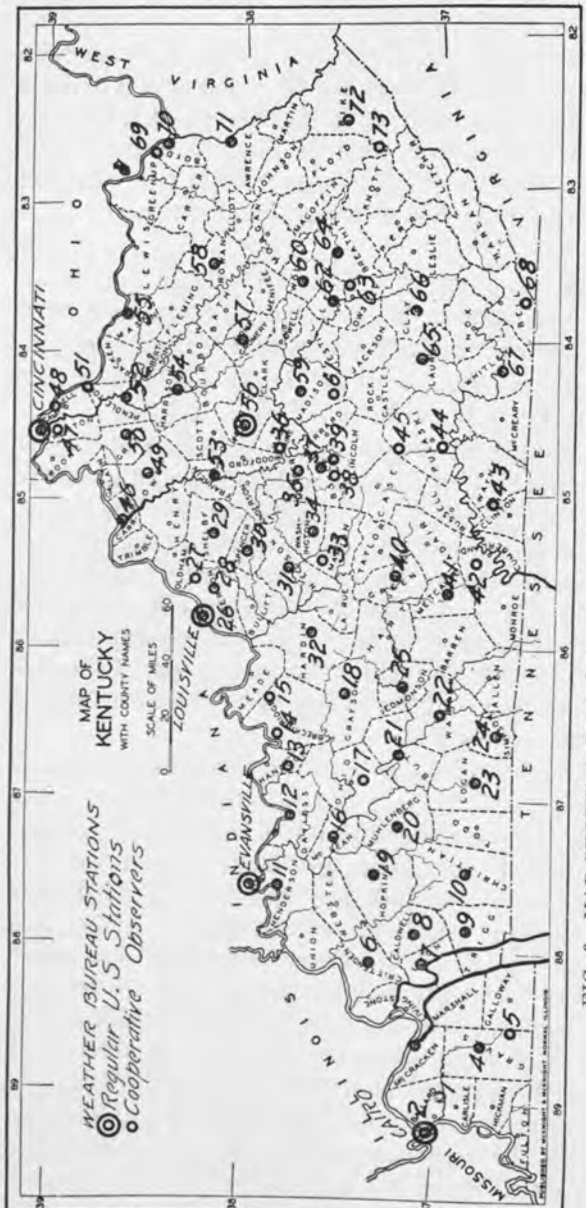


FIG. 3. MAP SHOWING WEATHER BUREAU STATIONS IN KENTUCKY

Weather Bureau Stations. 1, Blandville; 2, Cairo, Illinois; 3, Paducah; 4, Mayfield; 5, Yynnville; 6, Marion; 7. Eddyville; 8. Princeton; 9. Cadiz; 10. Hopkinsville; 11. Henderson; 12. Owensboro; 13. Pellville; 14. Cloverport; 15. Irvington; 16. Calhoun; 17. Beaver Dam; 18. Leitchfield; 19. Earlington; 20. Greenville; 21. Woodbury; 22. Bowling Green; 23. Rushville; 24. Franklin; 25. Brownsville; 26. Louisville; 27. Anchorage; 28. Springdale; 29. Shelbyville; 30. Taylorsville; 31. Bardstown; 32. St. John; 33. Loretto; 34. Springfield; 35. Harrodsburg; 36. High Bridge; 37. Shelby City; 38. Danville; 39. Junction City; 40. Greensburg; 41. Edmonton; 42. Marrowbone; 43. Alpha; 44. Burnside; 45. Eubank; 46. Carrollton; 47. Scott; 48. Ft. Thomas; 49. Owenton; 50. Williamstown; 51. Caddo; 52. Falmouth; 53. Frankfort; 54. Cynthiana; 55. Maysville; 56. Lexington; 57. Mt. Sterling; 58. Farmers; 59. Richmond; 60. Campton; 61. Berea; 62. Beattyville; 63. South Fork; 64. Jackson; 65. London; 66. Manchester; 67. Williamsburg; 68. Middlesboro; 69. Ashland; 70. Catlettsburg; 71. Louisa; 72. Pikeville; 73. Weeksbury. A station is now operated at Munfordville in Hart County, Ky.

The considerable extension of Kentucky east and west (about 7½°, or 380 miles) is less significant than the far lesser distance between the southern and northern borders, because except where mountains intervene, contrasts along parallels are

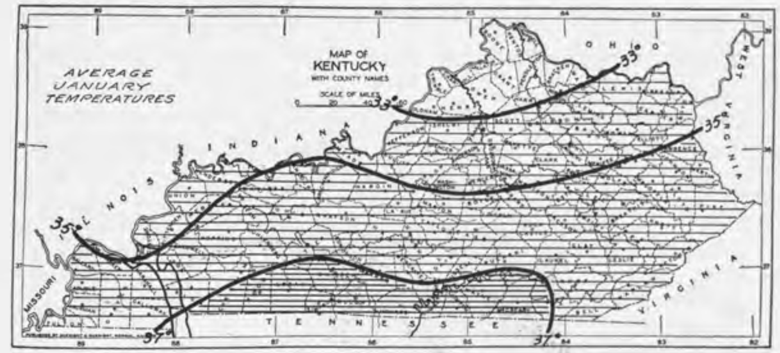


Fig. 4. The average temperature for the month of January ranges from about 32° at the extreme north Kentucky to about 37° at the south.

commonly not rapid. Westernmost Kentucky, however, is distinctly nearer the center of the continent than is the eastern tip of the state, and is therefore in a region of less average rainfall, hotter summers and more cold waves in winter. Cold waves are less frequent in eastern Kentucky partly because of the protective effects of the Appalachian Mountains, which tend to interfere somewhat with the passage of cyclonic disturbances.

The contrast in elevation in Kentucky is considerable, much of the lower western part being within 500 feet of sea-level while small areas of the southeast are above 2000 feet. The elevations of the Weather Bureau stations are given in the third column of Table 1. Paducah (341 feet), Mayfield (364 feet), Cloverport (375 feet), and Henderson (382 feet) are the only ones given as less than 400 feet. Nine stations are between 400 and 500 feet elevation, twenty are between 500 and 600, twenty-nine stations are between 600 and 1000 feet, six are from 1000 to 1200 feet, one (near Weeksbury) is at 1216 feet, and the highest (near Manchester) is at 1400 feet. Thus the range in elevation between the stations is only slightly over 1000 feet, and if the highest station be excepted, only about 800 feet. Most of the stations are situated at altitudes of from about 500 feet to about

900 feet. Hence, the effect of altitude is not very marked. It is seen, however, on a number of maps. The mountains of the southeastern border of Kentucky reach elevations of over 4000 feet (Big Black 4150 feet), and although there are no regular weather bureau stations in Kentucky above 1400 feet, it is known, from stations in the Appalachian Mountains of neigh-

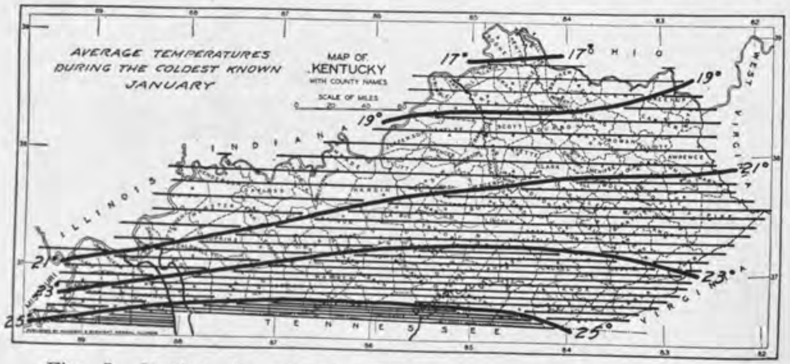


Fig. 5. During the coldest January of record, January, 1918, the average temperature for the month ranged from 17° F. at the extreme north to about 25° at the southern margin. The temperatures at Lexington, Louisville and Cairo were each about 14° below normal.

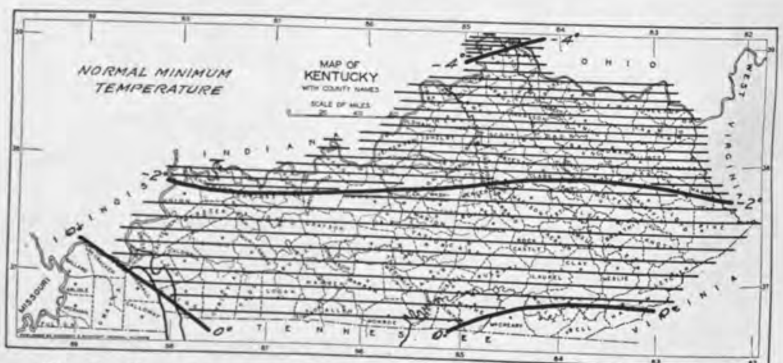


Fig. 6. Freezing temperature occur on some 70 to 85 days each winter, being most frequent at the north. Zero temperatures occur on an average of one or two days every year in all but extreme southwest and southeast Kentucky, and temperatures as cold as 4° below occur normally each year in northern Kentucky. Occasionally much lower temperatures are experienced. The records at main weather bureau stations in and bordering Kentucky are: Lexington and Louisville both, —20°; Cincinnati, —17°; Evansville and Cairo, both —16°. Cooperative stations with records of 25° or more below zero are: Bardstown (—25°), Earlington (—28°), Greensburg (—29°), Irvington (—25°), Leitchfield (—26°), Loretto (—30°), St. John (—26°), Shelby City (—28°). Since 20° below has occured thus widely in Kentucky and also at Nashville, Tennessee, the Weather Bureau considers that all of Kentucky is liable to a temperature of —20° except the southwest tip.

boring states, that climatic conditions are appreciably different at these higher elevations. Upon some of the following maps, the tiny areas above 2000 feet are shown to have a different climate from adjacent lower regions in Kentucky. Such a differentiation doubtless could have been made on additional maps.

Not only is the contrast in elevation not great among the Weather Bureau stations of Kentucky, but because of the local contrast in relief, nearby stations in some cases show almost as much contrast in elevations as stations which are more remote. This is because much of Kentucky is a rolling plateau into which deep valleys have been cut. A station on the upland may be 400 feet higher than a nearby one in the valley.

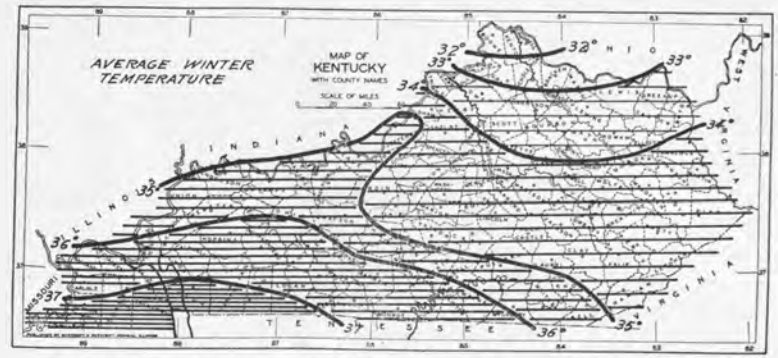


Fig. 7. The average winter (December, January, February) temperature increases from north to southwest from about 32° to about 37° F.

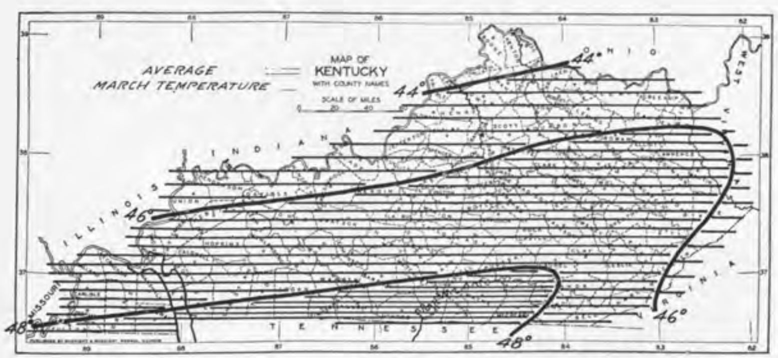


Fig. 8. The average temperature for March increases from about 44° at the extreme north to about 48° at the south, except at the southeast, which is cooler.

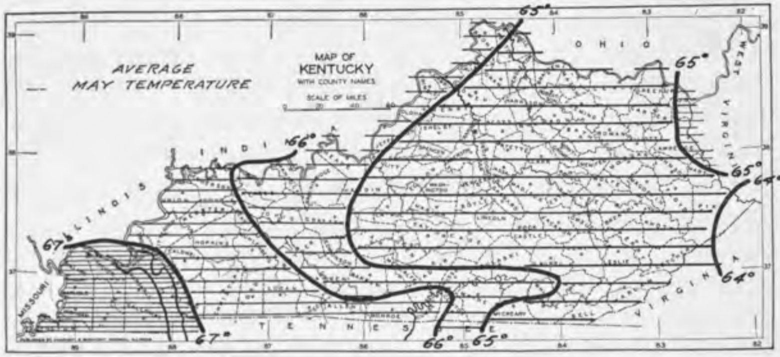


Fig. 9. Most of Kentucky has an average temperature of about 65° in May. However the lower western counties average about 67° and the highest eastern tip, about 64°.

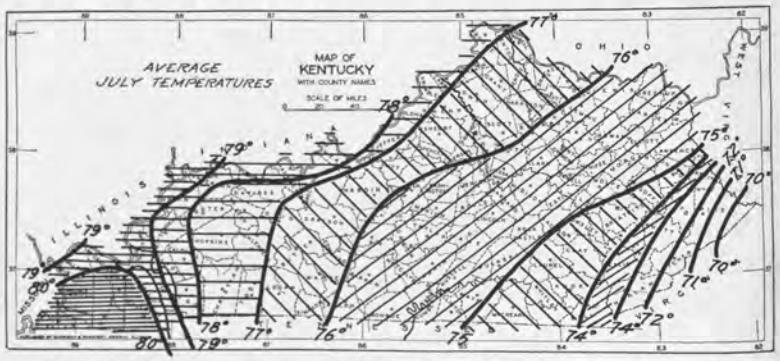


Fig. 10. The average temperature for July ranges from about 80° at the extreme west to about 70° at the extreme east, but most of the state has an average close to 76°.

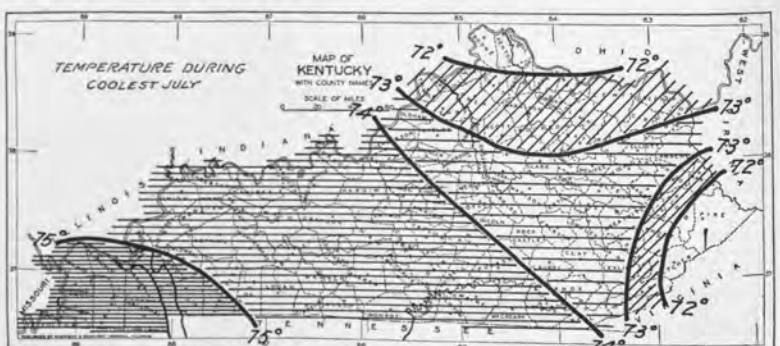


Fig. 11. During the coolest July on record in Kentucky (July, 1891) the temperature averaged about 72°, or 4 below normal at the extreme north, and about 75°, or 4 below normal at the southwest. Thus the coolest July was only slightly below normal, but the coldest January was nearly 15° below normal, on the average.

Because of these topographic conditions, the influence of relief is not clearly shown in most of the following maps. This is a great contrast to maps showing the climate of such states as New York, Colorado or California, where there are distinct re-

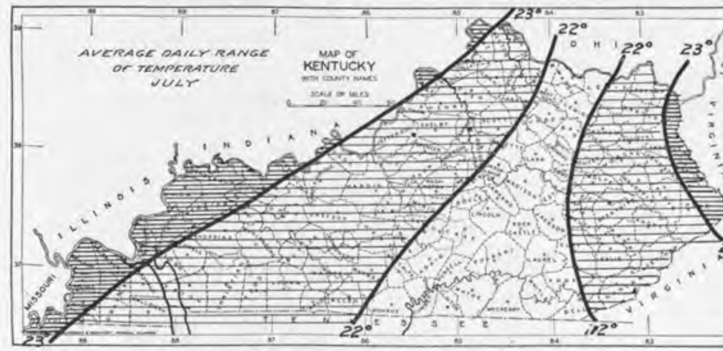


Fig. 12. On the average for July the highest temperature in the afternoon is about 22° higher than the lowest temperature (sunrise). The range is about a degree greater at the east and at the west. In January, the average range is less, about 18°, ranging from about 17° at the north to 19° at the central south.

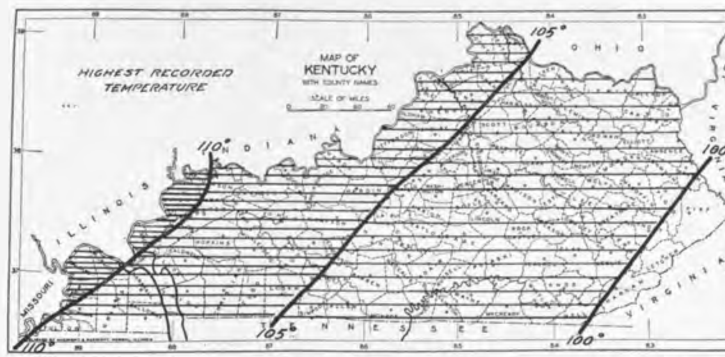


Fig. 13. Temperature of 110° or slightly over have been recorded at the extreme west, while the highest temperature officially recorded from the highest lands of the eastern margin is less than 100°.

gional contrasts in elevation. In New York, for example, the Adirondacks stand out clearly on nearly all detailed climatic maps of the state. Because of their direction, the outliers of the Appalachian Mountains situated on the southeastern border of Kentucky have less influence on the climate of the state than their elevation would suggest. They trend approximately parallel

with the prevailing winds and with the paths of cyclonic disturbances. Hence only the winds from some northwesterly direction ascend their Kentucky slopes abruptly. Winds from the northwest in the northern hemisphere are normally dry enough so that considerable cooling is required to cause them to drop much moisture. Nevertheless, southeastern Kentucky receives more rainfall than other parts of the state, and the heavier rainfall is attributed more to the mountains than to the nearness to the Atlantic Ocean, for relatively little rainfall is carried westward from the Atlantic Ocean as far as eastern Kentucky. The mountains to the east of Kentucky cooperate with the prevailing westerly winds to prevent this. The mountains increase the rainfall in Kentucky partly by giving rise to local convectional over-

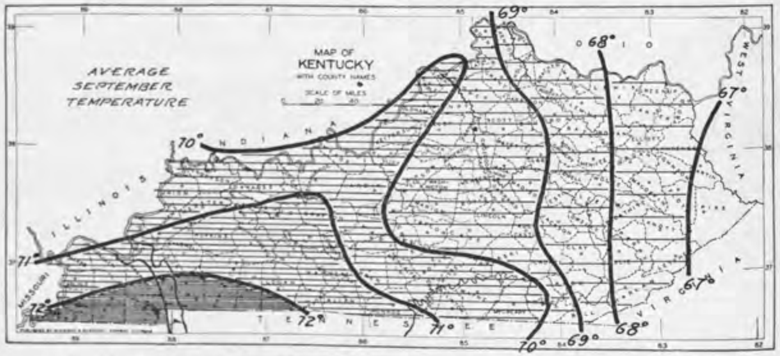


Fig. 14. Most of the state has an average temperature close to 70° in September, but the southwest margin is about 72°, and the eastern tip about 67°.

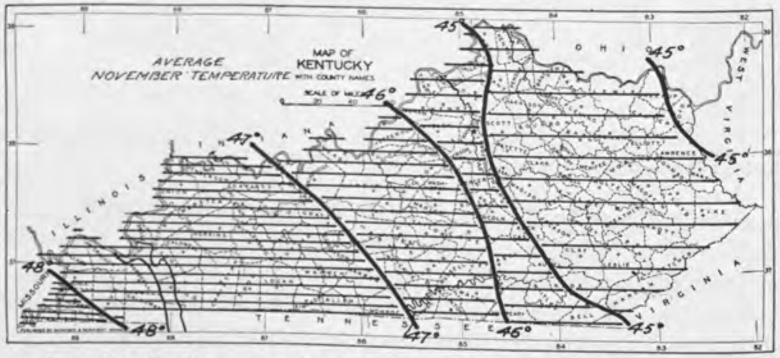


Fig. 15. In November the average temperature is about 45° in the eastern half of the state and about 47° in the western half.

turning, producing thunder showers. Local contrasts are considerable in a state such as Kentucky, with its many deep valleys,

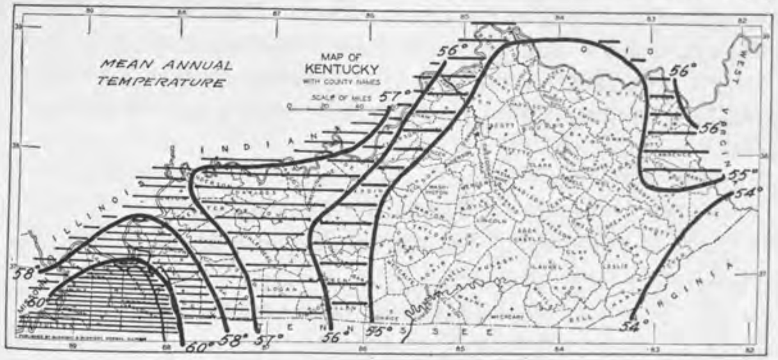


Fig. 16. The mean annual temperature ranges from about 58° in the southwestern counties to about 55° in the eastern half. It is somewhat lower in the mountains of the southeast. Thus there is less contrast in annual average temperature than during summer or winter. Furthermore the mean annual temperature is close to that most favorable for man, but the mean annual is made up of summers which are too hot, and winters are occasionally too cold.

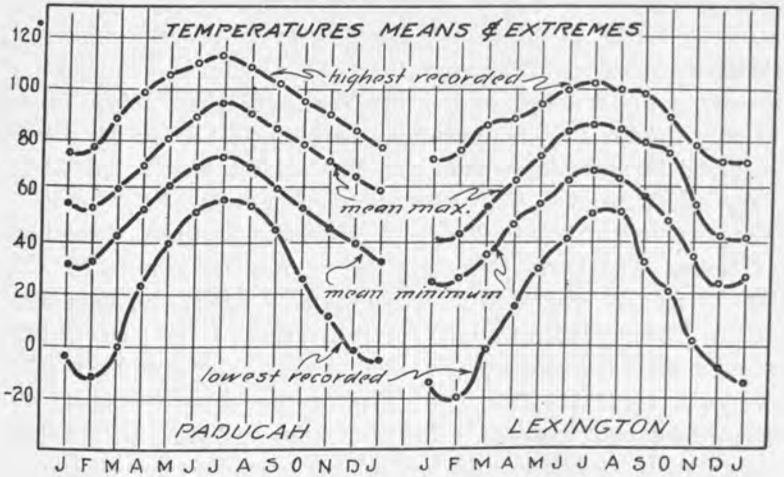


Fig. 17. Temperatures at Paducah, western Kentucky; means and extremes during 17 years. (From D. H. Davis, Geography of the Jackson Purchase, Kentucky Geological Survey, 1923.)

Fig. 18. Temperatures at Lexington, eastern central Kentucky; means and extremes during a 41-year period.

and slopes at different angles. These local contrasts are only slightly shown on the following maps. It should be recalled, however, that within any zone shown on the following maps,

localities in a deep valley, or on a steep slope at considerably higher altitude differ appreciably in temperature, frost, fog, strength of wind and in relative humidity. The direction of the wind sometimes is modified. On the average, winds tend to blow through gaps rather than to ascend over hills. But hot winds sometimes blow strongly up steep slopes with a sort of chimney effect.

Climatic Ranges in Kentucky

A brief summary of the state's climate is given in the following four paragraphs.

The mean annual temperature ranges from somewhat below 54° in the eastern highlands to about 59° at the west and south. The average temperature of the three summer months ranges from about 71° at the east to 80° at the lower west, and that of the three winter months between 32° at the north and 37° at the south. The average temperature in July, usually the warmest month, is about 75° to 77° in the most of eastern Kentucky and about 76° to 80° at the west. Temperatures of over 100° are occasionally experienced. The record is 112°. August is only slightly cooler on the average, and is often warmer than July. It is usually drier. Day temperatures as high as 75° to 84° have occurred in mid-winter months. The coldest months are January and February, with average temperatures of 33° to 38°. Temperatures of 10° to 20° below zero have occurred a number of times. The lowest temperatures in Kentucky were 20° to 30° below zero, recorded during February, 1899, and January, 1918. The prevailing winds for the year and for most of the months are southwesterly, but during the colder months, northwesterly winds are frequent. The average hourly velocity of the wind ranges from six to fourteen miles an hour. Gales occur occasionally, however, and one or two tornadoes somewhere in the state almost every year.

The average date of the last killing frost in spring ranges from April 9 at the extreme southwest to April 23 at the east, and the first killing frost in fall from October 13 at the southeast to October 23 at the west. Killing frosts have occurred, however, as late as May 15 and as early as September 14. The average number of consecutive days without killing frost ranges for all but the eastern and northern margins of the state, from 174 to 190 days.

The annual precipitation ranges from about 40 inches to about 50 inches, being least in the Licking River Basin and greatest in the southeast. The southwestern section of the state receives almost as much, 48 inches, on the average. The fluctuation from year to year is moderate, exceptionally wet years receiving about twice as much as exceptionally dry ones. For many parts of the world, the range from year to year is twice as great as in Kentucky. The fluctuations from month to month are moderate too, on the average, the driest month, October, receiving about 2½ inches on the average, whereas the wettest months, January, March and July, receive about four to five inches. Corresponding months of successive years, however, show considerable fluctuations, illustrated graphically in Figures 57-64. The driest July at Louisville, for example, received only 1.04 inches, in contrast to 16.46 in the wettest July. The wettest August received seventy times as much rain as the driest (10.5 vs. 0.15 inches). Usually during the growing season there is sufficient rain for each of the staple crops. Occasionally there is too much rain, especially during the spring months. Droughty conditions prevail for a few weeks nearly every summer somewhere in the state, the Blue Grass area, the lower Green River valley, and the southwestern counties being particularly subject to such spells. But usually, before the drouth has lasted long enough to be disastrous to the chief crops, thunder showers occur.

A measurable amount of rain or snow falls on each of about 104 days a year in the western half of Kentucky, and on about 108 days in the eastern half. Rainy days are least frequent in the autumn, five to nine days a month being so classed for September, October, and November. The remaining months of the year have from 10 to 13 days with some precipitation, on the average.

Further details of the climate may be found in tables 1-3, in Figures 4-105, and in the "Climatological Data for Sections 75 and 76 (United States Weather Bureau, 1925)."

TABLE 1.—WEATHER BUREAU STATIONS IN KENTUCKY

Name	County	Elevation	Part of State	No. on Fig. 3	Yrs. of Rec.*	Mean Precipitation												
						Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Alpha	Clinton	†811	S. C.	43	28	5.3	4.2	5.9	4.9	4.1	4.9	5.6	4.8	3.4	3.0	3.5	4.7	54.4
Anchorage	Jefferson	700	N. C.	27	24	3.8	2.9	4.5	3.9	3.7	3.6	3.4	3.8	2.6	2.9	3.4	4.0	43.3
Ashland	Boyd	534	N. E.	69	7	4.5	2.6	4.6	3.4	4.0	3.7	3.8	4.3	2.9	2.1	3.8	2.9	42.6
Bardstown	Nelson	637	C.	31	30	4.6	3.7	4.6	4.1	3.8	4.0	4.0	4.0	2.8	2.8	3.4	4.6	46.2
Beattyville	Lee	650	E. C.	62	20	4.7	3.9	5.1	4.2	4.2	4.5	4.8	4.5	3.1	3.3	2.9	4.4	49.5
Beaver Dam	Ohio	441	W. C.	17	20	4.2	3.2	4.2	4.1	4.2	3.2	4.0	3.3	2.7	2.8	3.2	3.8	42.8
Berea	Madison	1070	E. C.	61	22	4.7	3.2	4.9	3.7	3.9	4.5	4.7	4.6	2.9	3.0	3.1	4.5	47.7
Blandville	Ballard	445	W.	1	44	4.5	4.4	4.9	4.5	4.2	4.3	3.8	3.2	3.1	3.1	4.2	4.0	48.1
Bowling Green	Warren	500	S. W. C.	22	40	4.7	3.9	5.1	4.5	4.5	3.8	4.4	3.6	3.2	2.7	3.9	4.1	48.4
Brownsville	Edmonson	410	S. W. C.	25	6	5.6	3.9	6.9	5.4	4.3	3.6	3.1	4.0	3.5	3.1	4.8	3.8	52.1
Burnside	Pulaski	773	S. C.	44	37	4.7	4.3	5.3	4.3	4.2	4.2	4.9	4.1	3.5	2.9	3.3	4.2	49.9
Caddo	Pendleton	____	N. E.	51	10	4.2	4.0	5.2	3.7	3.6	4.6	4.0	3.0	2.4	2.6	4.7	3.3	45.2
Cadiz	Trigg	____	W.	9	8	3.6	4.4	4.2	3.6	4.7	3.3	4.9	2.0	3.3	3.1	3.7	5.2	46.2
Calhoun	McLean	437	W. C.	16	20	4.8	3.2	4.7	4.6	4.0	3.6	4.2	3.6	2.8	3.4	3.5	4.2	46.6
Canton	Trigg	____	S. W.	9	12	4.4	3.7	5.9	4.7	4.5	3.8	3.7	3.0	2.6	1.8	4.5	3.4	46.0
Carrollton	Carroll	422	N. C.	46	26	3.5	2.6	3.7	3.6	4.0	3.5	3.3	3.0	2.8	2.8	3.1	3.2	39.0
Catlettsburg	Boyd	544	N. E.	70	33	4.1	3.4	4.4	3.5	4.2	4.3	4.2	3.6	2.6	2.7	2.9	3.4	43.0
Cloverport	Breckinridge	375	N. W.	14	9	4.1	2.3	4.3	4.0	4.0	4.0	4.0	3.6	2.7	3.4	3.5	4.7	44.3
Cynthiana	Harrison	684	N.	54	6	3.3	2.1	4.6	4.5	3.4	3.0	2.5	4.8	3.7	3.3	3.5	4.0	42.6
Danville	Boyle	1000	C.	38	24	3.7	3.3	4.0	3.9	4.1	4.1	4.4	3.7	3.3	2.0	3.1	3.9	43.5
Earlington	Hopkins	420	W.	19	34	4.5	3.5	5.1	4.3	4.6	3.3	3.9	3.1	2.7	2.6	4.0	3.8	45.4
Eddyville	Lyon	436	W.	7	9	4.0	3.7	3.6	3.2	4.1	3.4	2.2	3.4	3.1	2.0	3.8	2.2	38.2
Edmonton	Metcalfe	600	S. C.	41	29	4.6	4.2	5.4	4.5	4.3	4.2	4.8	3.7	3.1	2.4	3.6	4.7	49.7
Eubank	Pulaski	1177	S. C.	45	30	4.4	3.6	5.1	3.9	4.3	4.1	4.5	4.2	3.5	2.9	3.3	4.1	47.9
Falmouth	Pendleton	600	N.	52	36	3.9	3.2	4.3	3.5	3.6	4.1	3.8	3.6	2.5	2.5	3.3	3.3	41.7
Farmers	Rowan	668	E. C.	58	19	4.2	2.9	5.1	4.2	3.9	4.3	4.7	4.6	2.9	3.3	3.0	4.0	47.0
Fort Thomas	Campbell	588	N.	48	26	3.0	2.3	3.2	3.3	4.2	4.1	4.1	3.1	3.4	2.2	3.5	3.4	39.9
Frankfort	Franklin	560	N. C.	53	40	4.0	3.6	4.6	3.9	3.8	4.1	3.8	3.5	2.9	2.5	3.3	3.7	43.9
Franklin	Simpson	691	S. W.	24	32	4.4	4.3	5.3	4.3	4.3	3.6	4.3	3.7	3.5	2.6	3.6	4.6	48.4
Greensburg	Green	581	C.	40	36	4.7	4.0	5.2	3.9	4.2	4.3	4.3	4.2	3.2	2.8	3.5	4.1	48.5
Greenville	Muhlenberg	519	W.	20	7	4.3	2.7	5.6	4.9	4.3	3.8	3.7	3.9	2.6	3.7	3.9	3.6	47.1
Harrodsburg	Mercer	850	C.	35	7	3.2	3.9	4.2	5.1	4.2	3.6	2.6	5.8	2.6	1.9	3.3	3.7	44.1
Henderson	Henderson	382	N. W.	11	16	3.3	2.5	5.4	3.6	3.9	4.1	3.3	2.7	2.8	3.2	3.9	4.3	43.2

TABLE 1.—WEATHER BUREAU STATIONS IN KENTUCKY—Continued

Name	County	Elevation	Part of State	No. on Fig. 3	Yrs. of Rec.*	Mean Precipitation												
						Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
High Bridge	Jessamine	550	C.	36	21	4.4	3.2	4.4	3.8	3.8	4.0	4.3	4.0	2.9	2.9	3.1	4.4	45.2
Hopkinsville	Christian	524	S. W.	10	27	5.2	3.6	5.1	4.5	4.1	4.1	3.9	3.2	3.1	3.0	4.1	4.7	48.6
Irvington	Breckinridge	646	N. W.	15	26	4.2	3.1	4.8	4.0	3.6	4.0	3.4	3.5	2.8	2.7	3.4	3.9	43.3
Jackson	Breathitt	776	E. C.	64	18	4.0	3.0	4.1	3.4	3.6	3.7	4.5	3.4	2.6	3.5	2.9	4.0	42.6
Junction City	Boyle	985	C.	39	7	6.6	3.8	5.6	4.7	4.4	3.6	4.6	3.8	3.2	3.7	3.4	4.7	52.4
Leitchfield	Grayson	635	W. C.	18	28	4.6	3.4	4.8	4.3	4.2	3.6	4.1	3.7	3.5	2.8	4.1	4.7	47.9
Lexington	Fayette	989	C.	56	63	4.2	3.9	4.3	3.8	3.9	4.2	3.8	3.6	3.2	2.5	3.3	3.9	44.5
London	Laurel	1190	S. C.	65	8	6.5	3.0	4.2	3.5	4.7	4.8	4.2	5.0	3.5	5.0	2.8	4.3	51.7
Loretto	Marion	681	C.	33	22	4.7	3.0	4.2	3.7	4.0	4.4	4.1	3.5	2.9	2.5	2.9	4.2	44.1
Louisa	Lawrence	584	N. E.	71	22	3.7	3.3	4.1	3.3	4.1	4.8	3.4	4.1	2.6	2.9	3.0	3.5	42.9
Louisville	Jefferson	525	N. W.	26	57	4.0	3.7	4.4	4.1	3.7	4.0	3.9	3.3	2.7	2.7	3.7	3.8	44.0
Louisville 2	Jefferson	534	N. W.	26	14	4.4	2.8	4.5	4.5	3.6	3.6	5.1	4.1	3.0	3.3	3.2	4.3	46.5
Lynnville	Graves	____	S. W.	5	5	4.3	5.6	4.1	4.8	5.3	3.1	5.7	2.8	3.1	3.6	6.7	3.9	53.0
Manchester	Clay	1400	S. E.	66	13	4.0	2.9	4.6	3.3	2.9	5.3	4.1	5.0	2.9	2.7	2.3	4.5	44.6
Marion	Crittenden	571	W.	6	29	4.7	3.1	4.8	4.4	3.3	3.6	3.7	2.9	3.0	2.7	3.8	4.2	45.4
Marrowbone	Cumberland	719	S. C.	42	11	4.3	3.2	6.4	4.4	3.3	3.4	5.5	2.8	3.3	1.6	3.0	4.5	45.8
Mayfield	Graves	364	W.	4	11	3.4	2.5	5.2	4.4	3.7	2.6	3.2	3.6	2.9	2.4	3.6	4.5	42.0
Maysville	Mason	524	N.	55	27	4.0	3.1	4.6	3.6	4.1	4.0	4.3	3.8	2.8	2.7	3.0	3.8	44.0
Middlesboro	Bell	1128	S. E.	68	32	4.7	4.5	5.6	4.6	4.0	4.7	5.3	4.5	2.7	2.7	3.3	4.7	51.2
Mt. Sterling	Montgomery	930	E. C.	57	34	4.6	3.9	5.5	4.1	4.2	4.8	4.9	4.1	3.0	2.9	3.3	4.3	49.7
Owensboro	Daviess	479	W. C.	12	27	4.2	2.9	4.8	4.1	3.8	3.5	3.5	3.3	2.8	3.2	3.4	3.8	43.4
Owenton	Owen	700	N. C.	49	20	4.4	4.2	5.2	3.2	4.3	4.0	4.7	2.8	2.8	2.2	4.0	3.9	45.8
Paducah	McCracken	341	W.	3	41	4.2	3.6	4.6	4.2	3.8	3.7	3.6	3.5	2.6	2.8	4.0	3.8	44.4
Paducah 2, Lone Oak	McCracken	516	W.	3	7	4.9	2.2	6.2	5.6	3.9	3.7	2.8	4.6	3.2	3.6	4.3	4.8	49.8
Pellville	Hancock	533	N. W.	13	6	3.5	4.2	4.5	4.2	3.9	3.3	2.5	3.7	2.8	1.9	4.1	3.2	41.9
Pikeville	Pike	634	E.	72	19	4.1	3.4	4.4	3.7	3.3	4.3	4.1	4.1	3.2	2.9	2.7	3.9	44.2
Princeton	Caldwell	529	W. C.	8	25	4.2	4.5	5.4	4.0	4.9	3.7	3.7	3.4	2.8	2.4	4.1	4.3	47.4
Richmond	Madison	926	C.	59	37	4.3	3.5	4.5	3.5	3.6	3.8	4.3	3.6	2.9	2.7	3.0	4.0	43.6
Russellville	Logan	590	S. W.	23	15	5.4	3.5	5.7	5.0	4.1	3.0	4.5	2.4	3.1	2.2	3.6	3.6	46.3
St. John	Hardin	777	W. C.	32	27	4.5	3.7	5.0	4.0	4.0	3.9	3.5	3.8	3.0	2.8	3.6	4.5	46.3
Scott	Kenton	900	N.	47	26	3.8	2.6	4.6	3.3	4.0	3.5	3.4	3.6	2.6	2.8	2.9	3.3	40.5
Shelby City	Boyle	1087	C.	37	24	4.3	3.7	5.0	3.7	3.8	3.7	4.2	3.5	3.0	2.2	3.2	4.4	44.9
Shelbyville	Graves	304	N. W. C.	29	35	4.2	3.6	4.9	3.8	4.0	4.3	3.9	3.5	2.8	2.6	3.6	4.0	45.4

TABLE 1.—WEATHER BUREAU STATIONS IN KENTUCKY—Continued

Name	County	Elevation	Part of State	No. on Fig. 3	Yrs. of Rec.*	Mean Precipitation												
						Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
South Fork	Owsley	981	E. C.	63	11	4.8	3.6	6.0	3.6	4.2	4.2	5.3	2.3	3.4	2.0	3.0	3.3	45.6
Springdale	Jefferson	570	N. W. C.	28	31	3.4	3.7	4.6	4.4	4.6	5.0	4.2	3.9	3.1	3.0	3.7	4.7	48.4
Springfield	Washington	738	C.	34	7	3.7	2.9	3.9	4.1	4.8	3.7	4.6	2.1	3.0	1.7	3.7	4.0	42.3
Taylorsville	Spencer	489	C.	30	21	4.5	3.5	4.6	4.4	3.6	4.1	4.3	3.8	3.1	3.0	3.2	4.5	46.6
Weeksbury	Floyd	1216	S. E.	73	7	4.8	2.7	3.0	3.0	3.1	4.2	4.9	6.0	2.8	3.7	2.0	4.5	44.7
Williamsburg	Whitley	939	S. E.	67	36	4.6	3.9	4.8	4.1	4.3	4.6	5.1	4.8	3.2	2.7	3.1	3.7	49.0
Williamstown	Grant	943	N.	50	21	3.6	2.7	4.4	3.4	3.6	3.7	3.7	4.1	2.9	2.9	2.6	3.5	41.3
Woodbury	Butler	533	S. W. C.	21	9	4.5	3.5	4.6	4.4	3.6	4.1	4.3	3.8	2.1	3.0	3.2	4.5	46.6

*Up to 1922.

†The cooperative observer lives, in many cases, at some distance from the town and at higher or lower altitude.

TABLE 2—TEMPERATURES AT WEATHER BUREAU STATIONS IN KENTUCKY

STATION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Alpha (21 years)													
Mean temperature	40	39	50	58	66	72	76	75	70	60	50	41	58
Mean maximum temperature	47	48	58	67	75	80	83	83	79	69	59	48	66
Mean minimum temperature	32	31	42	49	58	64	68	67	61	50	41	34	50
Highest recorded temperature	77	76	88	92	98	98	100	100	100	90	83	72	100
Lowest recorded temperature	—12	—19	—3	24	32	42	50	50	33	25	9	—7	—19
Anchorage (22 years)													
Mean temperature	33	33	45	54	65	72	76	75	69	57	45	34	55
Mean maximum temperature	43	43	56	66	76	84	89	87	82	70	56	43	66
Mean minimum temperature	24	23	34	43	53	60	64	63	56	44	33	25	43
Highest recorded temperature	74	78	87	90	97	104	107	102	100	93	80	70	107
Lowest recorded temperature	—16	—12	4	9	30	37	45	43	32	21	8	—20	—20
Bardstown (26 years)													
Mean temperature	35	35	47	56	67	75	78	77	72	59	47	37	57
Mean maximum temperature	44	45	58	67	79	87	91	89	85	73	58	45	69
Mean minimum temperature	26	26	36	44	54	62	66	65	58	46	36	28	46
Highest recorded temperature	73	78	90	94	102	105	108	106	104	95	85	72	108
Lowest recorded temperature	—14	—25	2	22	31	39	49	46	29	20	9	—16	—25
Beattyville (18 years)													
Mean temperature	35	36	46	54	64	73	76	75	70	58	45	36	56
Mean maximum temperature	47	48	60	69	79	86	89	88	84	73	59	47	69
Mean minimum temperature	23	23	32	40	50	59	62	62	56	42	40	24	42
Highest recorded temperature	76	77	90	96	97	105	107	104	100	95	84	75	107
Lowest recorded temperature	—18	—14	0	17	29	36	44	45	32	17	6	—19	—19
Beaver Dam (19 years)													
Mean temperature	35	36	48	56	66	74	78	76	71	59	47	37	57
Mean maximum temperature	45	47	59	68	79	87	90	89	85	73	59	47	69
Mean minimum temperature	25	26	36	44	54	62	65	64	60	44	34	27	45
Highest recorded temperature	75	82	90	90	103	108	105	104	103	96	83	74	108
Lowest recorded temperature	—20	—8	6	24	30	39	47	45	32	23	8	—19	—20
Berea (20 years)													
Mean temperature	36	37	48	56	66	73	76	74	69	59	47	37	57
Mean maximum temperature	46	47	59	68	77	85	87	86	82	72	59	46	68
Mean minimum temperature	27	27	36	44	54	61	64	63	57	46	36	27	45
Highest recorded temperature	76	76	88	89	96	101	104	102	98	96	79	73	104
Lowest recorded temperautre	—14	—12	4	20	30	37	46	44	31	20	6	—21	—21
Blandville (28 years)													
Mean temperature	36	36	48	57	67	75	78	77	71	60	48	38	58
Mean maximum temperature	44	45	57	67	76	85	88	86	81	70	58	45	67
Mean minimum temperature	28	28	39	48	57	65	68	67	61	49	39	30	48
Highest recorded temperature	75	79	88	92	98	102	108	107	102	94	84	75	108
Lowest recorded temperature	—18	—15	4	24	31	43	53	47	32	16	1	—10	—18
Bowling Green (27 years)													
Mean temperature	37	38	49	58	68	76	79	78	72	60	48	38	58
Mean maximum temperature	47	48	60	70	81	89	92	90	85	74	60	47	70
Mean minimum temperature	27	27	38	45	55	63	67	65	59	46	36	29	46
Highest recorded temperature	75	78	91	94	100	105	108	106	103	94	88	76	108
Lowest recorded temperature	—11	—17	2	22	31	39	50	41	28	20	5	—10	—17
Calhoun (19 years)													
Mean temperature	36	37	49	58	68	75	79	77	71	61	48	38	58
Mean maximum temperature	46	48	60	69	79	87	91	90	84	74	60	47	70
Mean minimum temperature	27	28	38	46	56	63	66	65	58	47	37	29	47
Highest recorded temperature	74	79	90	91	98	103	106	105	103	96	83	72	106
Lowest recorded temperature	—15	—7	9	24	35	40	51	45	30	21	9	—9	—15
Catlettsburg (9 years)													
Mean temperature	36	33	47	55	66	72	77	76	70	58	47	36	56
Mean maximum temperature	46	43	59	67	78	84	88	88	84	72	60	46	68
Mean minimum temperature	26	22	36	43	53	61	65	64	57	43	35	27	44
Highest recorded temperature	78	76	91	95	93	99	100	104	99	91	83	70	104
Lowest recorded temperature	—5	—22	3	17	31	45	51	50	28	25	11	—11	—22
Earlington (28 years)													
Mean temperature	35	36	48	57	67	76	79	77	71	59	48	38	58
Mean maximum temperature	45	45	58	69	79	88	91	89	85	73	59	46	69
Mean minimum temperature	26	26	38	45	55	63	66	64	58	46	37	29	64
Highest recorded temperature	76	81	90	93	105	107	107	111	106	97	85	74	111
Lowest recorded temperature	—16	—28	5	22	32	40	47	42	32	24	7	—14	—28
Edmonton (24 years)													
Mean temperature	37	37	48	56	65	73	76	75	70	57	47	37	57
Mean maximum temperature	46	47	60	67	78	85	87	87	82	71	59	47	68
Mean minimum temperature	27	26	37	44	53	61	65	64	37	44	35	28	45
Highest recorded temperature	78	77	88	89	95	103	106	102	101	93	80	75	106
Lowest recorded temperature	—15	—24	1	19	30	38	47	49	31	21	5	—14	—24
Eubank (28 years)													
Mean temperature	35	35	46	54	64	71	75	74	68	57	45	36	55
Mean maximum temperature	45	46	58	67	77	84	87	86	81	71	57	46	67
Mean minimum temperature	25	24	35	42	51	59	63	62	55	43	33	26	43
Highest recorded temperature	73	74	87	94	99	99	103	102	101	93	81	69	103
Lowest recorded temperature	—14	—22	—2	19	29	35	45	44	30	19	5	—16	—22

TABLE 2—TEMPERATURES AT WEATHER BUREAU STATIONS IN KENTUCKY—Continued

STATION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Farmers (14 years)													
Mean temperature	35	35	45	55	64	70	75	74	68	57	45	36	55
Mean maximum temperature	45	47	58	68	77	84	88	87	82	72	58	46	68
Mean minimum temperature	24	23	33	41	50	58	62	61	54	42	31	25	42
Highest recorded temperature	78	79	88	93	97	102	104	101	100	94	81	73	104
Lowest recorded temperature	—16	—15	0	18	29	38	42	44	29	18	8	—20	—20
Franklin (20 years)													
Mean temperature	39	39	51	58	67	75	79	77	70	61	49	39	59
Mean maximum temperature	48	49	61	70	78	86	89	88	79	73	60	48	69
Mean minimum temperature	29	29	40	47	56	64	68	66	61	49	39	30	48
Highest recorded temperature	78	76	89	91	98	103	102	101	102	95	82	73	103
Lowest recorded temperature	—14	—11	9	25	33	42	51	43	38	24	7	—6	—14
Frankfort (26 years)													
Mean temperature	36	35	47	56	66	74	77	75	69	58	47	37	56
Mean maximum temperature	45	45	58	67	77	85	88	86	81	70	57	46	67
Mean minimum temperature	26	26	36	44	54	62	66	65	58	46	36	28	46
Highest recorded temperature	76	76	86	91	99	104	103	101	98	90	80	71	104
Lowest recorded temperature	—12	—16	8	21	32	41	45	41	31	27	10	—5	—16
Greensburg (26 years)													
Mean temperature	35	35	47	55	65	73	77	75	70	57	45	36	56
Mean maximum temperature	46	46	59	68	78	86	89	88	84	72	59	47	68
Mean minimum temperature	24	23	34	42	52	60	64	63	55	42	32	26	43
Highest recorded temperature	82	78	89	93	97	105	109	104	105	96	82	72	109
Lowest recorded temperature	—17	—29	2	17	27	37	42	42	29	19	8	—14	—29
Hopkinsville (26 years)													
Mean temperature	37	38	50	56	67	75	79	78	72	60	49	38	58
Mean maximum temperature	47	48	61	68	80	87	91	90	85	74	60	47	70
Mean minimum temperature	28	28	39	44	55	63	66	65	59	48	37	29	47
Highest recorded temperature	75	80	90	92	100	106	109	107	103	96	87	73	109
Lowest recorded temperature	—16	—19	3	24	33	41	50	47	34	22	5	—14	—19
Irvington (25 years)													
Mean temperature	36	35	48	55	66	74	77	76	71	59	47	37	57
Mean maximum temperature	44	44	58	66	77	84	88	86	81	70	56	44	67
Mean minimum temperature	27	26	38	45	56	64	67	66	60	48	37	29	47
Highest recorded temperature	73	78	87	87	96	102	105	101	98	93	79	73	105
Lowest recorded temperature	—15	—25	2	22	32	41	50	45	29	25	10	—13	—25

STATION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Junction City (7 years)													
Mean temperature	35	38	48	55	64	73	76	75	69	58	46	38	56
Mean maximum temperature	50	49	61	68	77	85	88	87	82	73	59	49	69
Mean minimum temperature	25	27	35	42	52	60	63	62	55	44	34	27	44
Highest recorded temperature	70	77	84	86	92	99	98	101	97	92	78	73	101
Lowest recorded temperature	—14	—3	—1	24	28	39	49	42	30	20	10	—19	—19
Leitchfield (27 years)													
Mean temperature	40	35	47	55	65	73	77	75	70	58	46	36	56
Mean maximum temperature	44	44	57	63	77	84	87	86	81	70	57	45	66
Mean minimum temperature	26	26	37	44	54	62	62	65	58	46	40	27	46
Highest recorded temperature	72	79	87	90	93	103	103	103	99	90	80	70	103
Lowest recorded temperature	—16	—26	1	20	29	40	50	47	28	23	8	—25	—26
Lexington (41 years)													
Mean temperature	34	34	44	54	64	73	76	74	69	57	45	35	55
Mean maximum temperature	41	42	53	63	73	82	85	83	78	67	53	43	64
Mean minimum temperature	26	26	35	44	55	64	67	65	59	48	36	28	46
Highest recorded temperature	72	75	85	88	93	99	102	100	98	89	78	71	102
Lowest recorded temperature	—14	—20	—1	15	30	40	51	46	32	21	2	—9	—20
Loretto (20 years)													
Mean temperature	36	35	47	55	66	73	76	76	70	58	46	36	56
Mean maximum temperature	47	46	59	68	78	85	88	88	83	72	59	46	68
Mean minimum temperature	26	23	35	42	53	60	64	63	56	44	34	25	44
Highest recorded temperature	83	78	90	89	96	103	106	105	102	92	79	70	106
Lowest recorded temperature	—18	—30	0	19	29	40	45	44	28	19	5	—16	—30
Louisville (53 years)													
Mean temperature	35	36	46	56	66	75	78	77	71	59	47	38	57
Mean maximum temperature	42	45	55	66	76	84	88	86	80	69	55	45	66
Mean minimum temperature	27	28	37	47	57	65	69	67	61	49	38	30	48
Highest recorded temperature	74	78	88	91	98	101	107	105	102	91	79	74	107
Lowest recorded temperature	—20	—14	3	21	33	43	54	47	36	23	4	—7	—20
Louisville (Cherokee Pk. (13 yrs.)													
Mean temperature	35	36	46	56	65	73	76	75	69	58	47	36	56
Mean maximum temperature	44	45	57	67	76	84	87	85	79	69	57	43	66
Mean minimum temperature	25	26	36	45	54	62	66	65	58	47	37	28	46
Highest recorded temperature	72	78	88	83	99	102	105	104	97	88	78	69	105
Lowest recorded temperature	—16	—7	9	22	33	41	52	44	36	26	6	—12	—16
Marion (25 years)													
Mean temperature	36	37	49	57	67	75	78	77	72	60	48	38	58
Mean maximum temperature	45	46	59	68	78	86	89	89	85	73	59	47	69
Mean minimum temperature	26	27	38	46	56	64	67	66	60	47	38	29	47
Highest recorded temperature	72	79	87	94	101	104	109	108	103	93	82	72	109
Lowest recorded temperature	—16	—7	9	22	33	41	52	44	36	26	6	—12	—16

TABLE 2—TEMPERATURES AT WEATHER BUREAU STATIONS IN KENTUCKY—Continued

STATION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Maysville (24 years)													
Mean temperature	33	32	45	53	65	73	77	76	70	58	45	34	55
Mean maximum temperature	43	43	57	67	78	86	91	89	84	72	57	44	67
Mean minimum temperature	22	22	33	40	51	60	64	62	55	43	33	24	42
Highest recorded temperature	80	76	89	94	100	105	108	105	103	95	82	72	108
Lowest recorded temperature	—16	—22	3	18	30	40	47	43	31	22	9	—20	—22
Middlesboro (23 years)													
Mean temperature	38	39	49	57	65	72	75	74	69	58	46	41	57
Mean maximum temperature	48	59	61	70	78	84	87	86	82	72	59	53	69
Mean minimum temperature	28	28	37	44	51	60	64	63	57	44	34	29	45
Highest recorded temperature	74	76	90	94	96	100	100	99	98	92	79	71	100
Lowest recorded temperature	—19	—20	3	15	30	36	47	43	30	20	7	—19	—20
Mt. Sterling (29 years)													
Mean temperature	33	33	45	54	65	73	76	74	68	56	44	35	55
Mean maximum temperature	41	42	55	65	76	84	87	85	80	68	54	43	65
Mean minimum temperature	25	24	35	43	53	61	65	63	57	45	34	27	44
Highest recorded temperature	73	76	85	90	98	102	104	102	97	92	79	71	104
Lowest recorded temperature	—14	—22	0	21	30	40	48	43	32	22	8	—18	—22
Owensboro (26 years)													
Mean temperature	35	35	47	55	66	74	78	76	71	59	47	37	57
Mean maximum temperature	43	44	57	66	77	85	88	86	81	70	57	45	67
Mean minimum temperature	26	27	37	45	56	64	67	66	60	48	37	29	47
Highest recorded temperature	73	79	89	92	94	102	103	101	101	92	80	75	103
Lowest recorded temperature	—17	—21	4	25	34	43	47	49	32	25	10	—14	—21
Owenton (13 years)													
Mean temperature	33	31	45	53	65	73	77	75	70	57	45	34	55
Mean maximum temperature	41	40	55	63	76	83	87	86	80	67	55	41	64
Mean minimum temperature	25	23	35	43	55	63	67	65	59	47	36	26	45
Highest recorded temperature	72	69	84	86	95	106	104	100	103	91	80	65	106
Lowest recorded temperature	—7	—19	2	20	31	38	51	48	31	24	11	—10	—19
Paducah (16 years)													
Mean temperature	38	37	50	59	70	78	81	81	76	61	50	39	60
Mean maximum temperature	46	45	59	69	80	89	92	92	85	73	59	47	70
Mean minimum temperature	30	28	41	49	59	67	71	70	67	50	40	31	50
Highest recorded temperature	76	77	78	94	98	102	112	105	104	95	82	78	112
Lowest recorded temperature	—3	—12	6	27	38	45	56	51	37	29	14	—3	—12

STATION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Richmond (26 years)													
Mean temperature	35	36	47	56	66	73	77	76	71	60	48	37	57
Mean maximum temperature	43	44	57	66	77	84	88	86	82	71	57	45	67
Mean minimum temperature	27	27	37	45	55	63	66	65	60	48	37	29	47
Highest recorded temperature	75	73	87	90	98	101	108	103	101	93	81	71	108
Lowest recorded temperature	—14	—24	0	21	30	40	50	38	30	21	8	—9	—24
Saint John (26 years)													
Mean temperature	34	34	46	54	65	73	76	75	69	58	46	35	55
Mean maximum temperature	43	44	56	66	76	84	87	87	82	71	57	44	66
Mean minimum temperature	24	24	35	43	53	61	64	63	57	45	34	26	44
Highest recorded temperature	71	78	88	90	96	103	106	102	100	93	89	70	106
Lowest recorded temperature	—16	—26	1	21	29	39	45	42	27	22	8	—19	—26
Scott (25 years)													
Mean temperature	32	32	44	53	64	72	76	75	69	58	45	33	54
Mean maximum temperature	41	41	54	64	75	82	87	86	81	69	55	41	65
Mean minimum temperature	24	23	34	42	53	61	65	64	57	46	35	25	44
Highest recorded temperature	80	74	88	89	97	100	107	102	102	92	80	73	107
Lowest recorded temperature	—16	—20	3	21	31	40	49	43	29	23	7	—16	—20
Shelby City (17 years)													
Mean temperature	35	33	46	54	65	72	76	74	69	58	45	35	55
Mean maximum temperature	45	44	57	67	78	84	88	87	83	72	58	44	67
Mean minimum temperature	25	23	34	41	52	60	63	62	56	44	33	25	43
Highest recorded temperature	73	78	88	93	99	103	104	105	105	96	89	70	105
Lowest recorded temperature	—9	—28	—3	20	28	37	45	44	30	20	7	—15	—28
Shelbyville (29 years)													
Mean temperature	33	33	46	54	65	74	77	76	70	58	45	35	55
Mean maximum temperature	42	43	56	66	78	86	90	89	83	71	56	43	67
Mean minimum temperature	24	24	35	42	53	61	65	63	56	44	34	26	44
Highest recorded temperature	76	75	92	93	102	105	107	106	103	94	83	71	107
Lowest recorded temperature	—16	—23	—3	19	28	38	46	44	28	18	8	—16	—23
Taylorsville (20 years)													
Mean temperature	34	35	47	55	65	73	76	74	68	56	45	35	55
Mean maximum temperature	44	45	57	66	77	84	88	85	80	69	56	44	66
Mean minimum temperature	25	25	36	43	53	61	64	63	56	44	33	27	44
Highest recorded temperature	74	76	87	88	95	102	104	103	99	89	77	71	104
Lowest recorded temperature	—18	—10	5	30	29	40	46	44	31	21	8	—20	—20
Williamsburg (24 years)													
Mean temperature	38	38	49	56	66	74	76	76	71	60	47	39	57
Mean maximum temperature	49	49	61	69	79	85	88	87	83	74	61	49	70
Mean minimum temperature	27	27	37	43	53	62	64	64	58	46	34	28	45
Highest recorded temperature	82	78	90	90	99	104	105	100	98	92	81	77	105
Lowest recorded temperature	—11	—19	2	19	31	41	47	48	32	20	10	—15	—19

TABLE 2—TEMPERATURES AT WEATHER BUREAU STATIONS IN KENTUCKY—Continued

STATION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Williamstown (19 years)													
Mean temperature	32	32	45	53	64	71	75	74	69	58	45	34	54
Mean maximum temperature	42	43	56	64	75	82	86	85	80	70	56	42	65
Mean minimum temperature	22	21	33	41	52	61	65	63	57	46	35	25	43
Highest recorded temperature	73	75	86	93	96	101	104	105	99	95	84	68	105
Lowest recorded temperature	—15	—11	4	20	30	37	43	42	33	23	7	—10	—15

TABLE 3—IRREGULARITIES OF PRECIPITATION

STATION	Mean Annual	Wettest Year*	Date	Driest Year*	Date	Wettest Summer Month*	Date	Driest Summer Month*	Date
Alpha	54.4	66.8	1915	38.6	1904	10.5	July, 1905	1.5	June, 1908
Anchorage	43.3	53.3	1909	29.3	1904	9.3	July, 1910	0.8	Aug., 1922
Ashland	42.6	50.6	1921	36.8	1889	10.7	Aug., 1888	1.1	Aug., 1889
Bardstown	46.2	61.2	1919	31.7	1904	9.7	July, 1909	0.3	July, 1921
Beattyville	49.5	58.1	1910	31.6	1904	8.7	July, 1910	1.7	Aug., 1917
Beaver Dam	42.8	50.3	1906	30.8	1904	13.2	July, 1910	0.6	Aug., 1904
Berea	47.7	60.4	1915	32.5	1904	10.8	July, 1910	1.6	June, 1921
Blandville	48.1	73.4	1882	30.7	1872	11.2	June, 1896	0.0	July, 1883
Bowling Green	48.4	63.0	1890	35.0	1901	10.7	July, 1910	0.2	July, 1901
Brownsville	52.1	65.8	1919	36.5	1918	7.2	Aug., 1920	1.2	June, 1918
Burnside	49.8	67.3	1890	40.4	1904	11.9	Aug., 1901	0.7	July, 1902
Caddo	45.2	54.9	1898	44.7	1890	8.4	June, 1891	0.6	July, 1894
Cadiz	46.2	51.3	1906	35.8	1904	10.7	July, 1910	0.2	Aug., 1909
Calhoun	46.6	57.1	1921	35.5	1904	11.0	July, 1910	0.7	July, 1914
Canton	46.0	55.9	1891	30.5	1894	11.8	June, 1900	0.1	June, 1899
Carrollton	39.0	50.5	1921	17.5	1901	8.2	July, 1910	0.4	July, 1901
Catlettsburg	43.4	65.3	1890	29.7	1904	10.1	June, 1906	1.0	Aug., 1908
Cloverport	44.3	60.0	1916	32.8	1914	7.5	June, 1916	0.6	Aug., 1922
Cynthiana	42.6	52.1	1919	35.5	1922	7.0	Aug., 1920	0.8	July, 1921
Danville	43.5	52.3	1865	35.9	1878	8.5	Aug., 1861	1.2	Aug., 1877
Earlington	45.4	56.2	1900	34.1	1918	12.0	July, 1910	0.3	June, 1914
Eddyville	38.3	48.2	1890	33.8	1889	6.6	June, 1889	0.5	July, 1890
Edmonton	49.7	59.7	1910	38.0	1904	12.1	July, 1910	0.4	July, 1901
Eubank	47.9	63.5	1915	31.6	1904	9.2	June, 1915	0.3	July, 1901
Falmouth	41.7	52.6	1890	26.3	1894	9.7	Aug., 1920	0.1	Aug., 1908
Farmers	47.0	56.6	1909	37.8	1914	8.2	Aug., 1912	1.2	June, 1914
Fort Thomas	39.9	58.1	1858	27.7	1856	9.6	July, 1860	0.5	Aug., 1889
Frankfort	43.9	58.6	1890	25.1	1901	10.8	Aug., 1888	0.2	Aug., 1895
Franklin	48.4	64.8	1919	29.8	1901	9.4	Aug., 1920	0.4	Aug., 1893
Greensburg	48.5	59.2	1890	32.4	1901	10.3	Aug., 1888	0.7	July, 1913
Greenville	47.1	55.9	1919	40.7	1918	7.7	Aug., 1921	0.8	Aug., 1922
Harrodsburg	44.1	49.4	1892	34.5	1894	7.2	Aug., 1891	0.5	June, 1872
Henderson	43.2	53.7	1921	34.3	1918	11.0	June, 1900	0.2	July, 1919
High Bridge	45.2	56.9	1919	27.2	1904	9.3	July, 1915	0.9	July, 1913
Hopkinsville	48.6	66.4	1919	36.7	1918	13.3	June, 1900	0.1	Aug., 1900
Irvington	43.3	53.3	1913	34.4	1904	8.7	July, 1910	0.4	July, 1898
Jackson	42.6	54.4	1917	36.3	1904	7.8	Aug., 1916	0.2	July, 1919
Junction City	52.4	57.2	1920	42.6	1918	6.9	July, 1916	1.5	Aug., 1918

TABLE 3—IRREGULARITIES OF PRECIPITATION—Continued

STATION	Mean Annual	Wettest Year*	Date	Driest Year*	Date	Wettest Summer Month*	Date	Driest Summer Month*	Date
Leitchfield	47.9	62.7	1906	36.6	1901	9.3	July, 1906	0.8	Aug., 1922
Lexington	44.5	63.3	1882	28.7	1904	11.2	July, 1875	0.6	Aug., 1875
London	51.7	60.4	1918	42.3	1916	8.2	Aug., 1914	1.0	Aug., 1917
Loretto	44.1	56.2	1915	30.2	1904	8.2	Aug., 1916	1.1	July, 1901
Louisa	42.9	63.3	1890	34.7	1894	14.0	June, 1888	0.2	July, 1894
Louisville	44.0	56.5	1882	29.5	1901	16.5	July, 1875	0.1	Aug., 1881
Louisville 2 (Cherokee Park)	46.5	55.4	1916	38.4	1920	13.6	July, 1910	0.9	Aug., 1909
Lynnville	53.0	54.8	1907	42.8	1908	9.3	July, 1910	0.3	Aug., 1909
Manchester	44.6	51.4	1902	40.8	1917	7.5	June, 1902	1.0	July, 1901
Marion	45.4	53.1	1910	30.8	1894	9.3	July, 1910	0.1	Aug., 1909
Marrowbone	45.8	53.9	1899	33.9	1901	8.6	July, 1897	0.8	Aug., 1900
Mayfield	42.0	51.4	1921	40.2	1904	6.9	July, 1904	0.4	July, 1918
Maysville	44.0	54.6	1920	31.6	1901	9.9	July, 1910	0.7	July, 1916
Middlesboro	51.2	65.3	1922	40.9	1895	10.8	Aug., 1901	0.9	Aug., 1896
Mt. Sterling	49.7	70.3	1909	37.3	1894	10.1	July, 1906	0.9	Aug., 1893
Owensboro	43.4	57.9	1907	32.5	1914	12.7	July, 1910	0.8	Aug., 1897
Owenton	45.8	55.8	1898	32.8	1901	9.9	July, 1909	0.3	Aug., 1889
Paducah	44.4	57.4	1883	27.7	1887	11.9	July, 1910	0.3	July, 1918
Paducah 2 (Lone Oak)	49.8	58.7	1919	46.9	1918	7.0	Aug., 1919	0.6	July, 1918
Pellville	41.9	53.0	1890	36.6	{1889 1892}	6.2	July, 1889	0.7	July, 1890
Pikeville	44.2	52.7	1917	33.4	1908	8.8	Aug., 1917	1.2	July, 1911
Princeton	47.4	64.8	1891	38.2	1893	11.5	June, 1900	0.05	Aug., 1900
Richmond	43.6	58.3	1898	27.3	1895	10.1	July, 1915	0.3	July, 1901
Russellville	46.3	51.2	1895	39.7	1894	8.9	July, 1895	0.6	Aug., 1893
St. John	46.3	58.9	1919	31.7	1901	9.9	Aug., 1915	0.3	July, 1913
Scott	40.5	51.1	1921	28.6	1901	8.5	Aug., 1915	0.6	Aug., 1904
Shelby City	44.9	58.3	1898	29.8	1894	10.9	July, 1896	0.7	July, 1894
Shelbyville	45.4	65.4	1890	32.2	1904	12.3	July, 1896	1.0	Aug., 1889
South Fork	45.6	47.5	1896	37.6	1895	9.3	July, 1896	0.8	Aug., 1889
Springdale	48.4	67.1	1850	30.9	1856	11.5	July, 1848	0.7	June, 1853
Springfield	42.3	42.6	1892	38.2	1894	7.9	July, 1896	0.3	Aug., 1889
Taylorsville	46.6	59.8	1906	32.0	1904	10.7	July, 1906	1.0	July, 1911
Weeksburg	44.7	51.5	1915	38.1	1916	8.3	July, 1915	2.8	June, 1914
Williamsburg	49.0	62.2	1890	33.6	1904	12.8	July, 1900	0.9	Aug., 1893
Williamstown	41.3	52.0	1911	28.1	1908	9.2	Aug., 1914	0.4	Aug., 1908
Woodbury	46.6	58.5	1919	36.3	1918	11.0	Aug., 1920	1.3	June, 1921

*Prior to 1923.

Hot Weather in Kentucky

Although temperatures of over 90° F. are very common during the summer half year in Kentucky and occasionally, as in 1913, temperatures of 100 F. or more occur on twenty to thirty

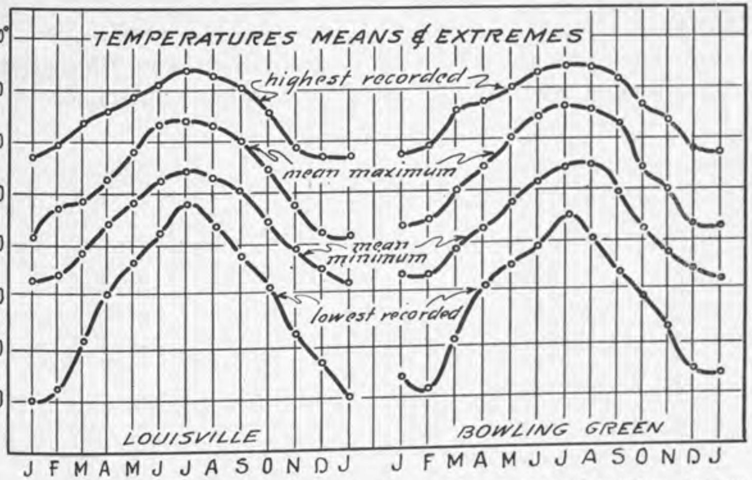


Fig. 19. Temperatures at Louisville, north central Kentucky; means and extremes during a 53-year period.

Fig. 20. Temperatures at Bowling Green, southwest Kentucky; means and extremes during a 27-year period.

days during the summer, nevertheless, Kentucky must not be thought of as having much more very hot weather than do states to the north and west. A very large area in the United States possesses similar temperatures during the hot spells of summer. During such hot periods, temperatures are often even higher in Indiana, Iowa, South Dakota and even in North Dakota than they are in Kentucky. This is partly because summer days are longer in states north of Kentucky. Furthermore, cloudiness is more common in Kentucky than in many western areas. Clouds reduce maximum temperatures. Kentucky, however, has a larger number of fairly hot days than do the states to the north and northwest, although the difference is not great, unless comparison is made with Minnesota, Wisconsin and Michigan. Parts of these three states farthest from the Great Lakes, however, occasionally have intensely hot spells. Although Kentucky is not notably warmer during hot periods than many other parts of the United States, nevertheless, the temperature is high enough in

Kentucky, as in many other areas, to be unfavorable for man's intellectual activity. Studies summed up in Huntington's Civilization and Climate, (1924), indicate clearly that the most favorable temperature for man is considerably below 68° F. Kentucky has a temperature above 68° most of the warmer half of the year. During the cooler half of the year, however, temperature conditions are distinctly favorable for man, being close to the optimum, and seldom low enough to be benumbing.

Excessive Rainfall

The rainfall is considered excessive when 2.5 inches fall in 24 hours or when the rate exceeds an inch an hour for at least a half-hour period. At Louisville, such excessive rainfalls occur about twice a year, on the average, and are known to have occurred in each of the twelve months. They are much more common during the summer than during the winter. At Lexington, in contrast, excessive rainfalls are much less frequent in winter than at Louisville.

The heaviest rainfall in 24 hours at Louisville was 5.5 inches, July 4, 1896, but March 1913 and October 1910 also received

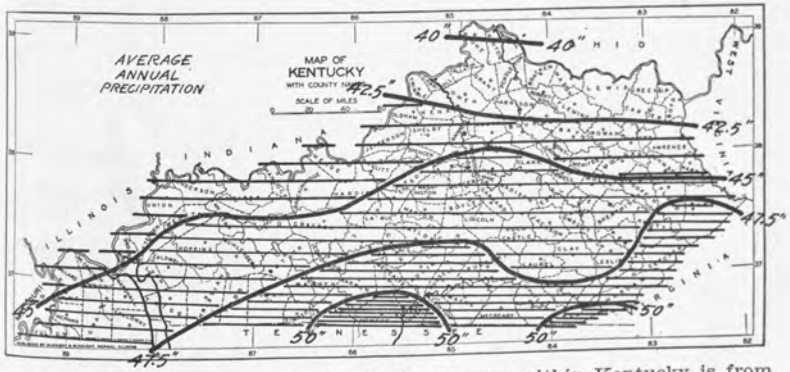


Fig. 21. Average annual rainfall. The range within Kentucky is from about 40 inches at the extreme north (Cincinnati, 38 inches) to over 50 in west and south central section. Within any of the belts shown on this map, however, there are considerable local contrasts due to the exposure of rain gauge, and to differences in the length of the record. See Table 1.

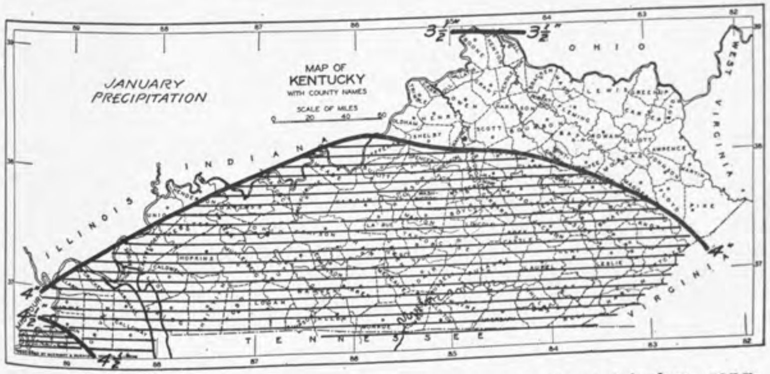


Fig. 22. The average precipitation in January is about 4 inches, ranging from about 3½ inches at the extreme north to about 4½ inches at the extreme southwest.

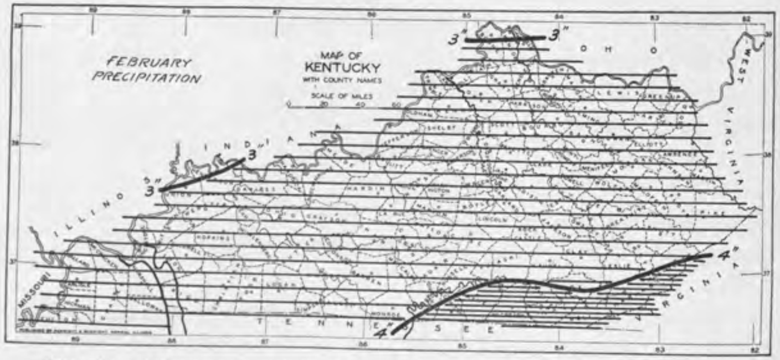


Fig. 23. February precipitation ranges, on the average, from 3 inches at the extreme north and northwest to 4 inches at the southeast.

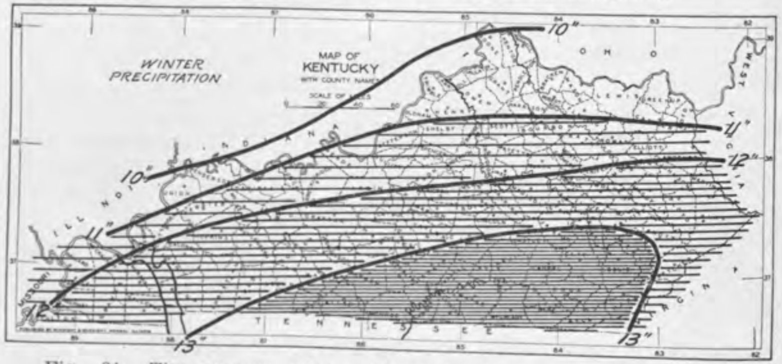


Fig. 24. The average winter (December-February) precipitation increases from 10 inches at the extreme north and northwest to nearly 14 inches at the southeast.

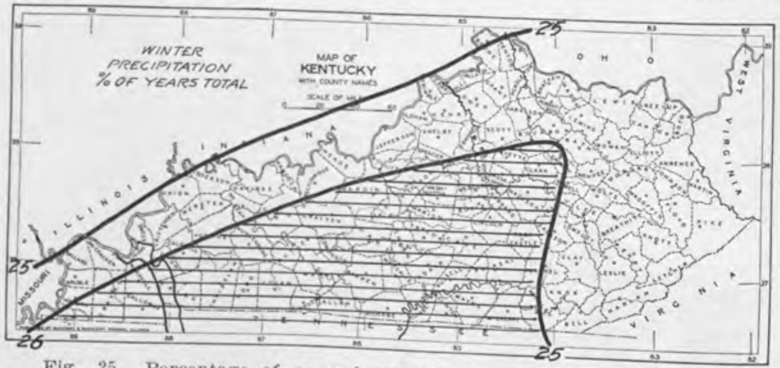
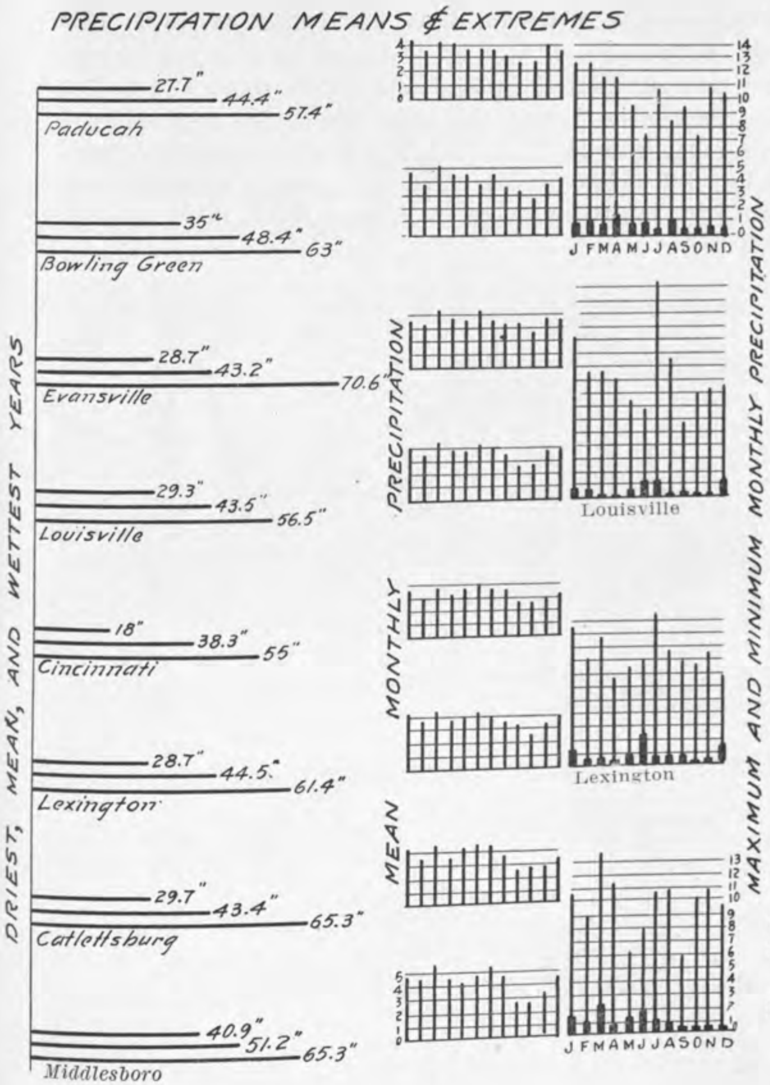


Fig. 25. Percentage of annual precipitation occurring in the winter months (December-February). All but four tiny areas at the extreme northwest and north receive more thane one-fourth of the year's precipitation during the winter quarter; the south central section receives nearly 27 per cent. Thus winter receives slightly more than its proportional share of rainfall.



Figs. 26-33. Diagrams showing the precipitation means and extremes (mean annual, wettest and driest years, mean monthly and wettest and driest month of each month at representative stations in Kentucky. Paducah, W. Kentucky, based on a 41-year record; Bowling Green, S. W. Kentucky, based on a 40-year record; Evansville, adjoining N. W. Kentucky, based on a 49-year record; Louisville, north central Kentucky, based on a 53-year period; Cincinnati, adjoining northern Kentucky, based on a 54-year record; Lexington, central Kentucky, based on a 40-year record; Catlettsburg, northeast Kentucky, based on a 33-year record; Middlesboro, southeast Kentucky, based on a 32-year record.

over five inches of rain in a 24-hour period. Months with maximum records of four to five inches are April, 4.1 (1880) and December 4.4 (1915). The remaining months have all received over three inches, although June has barely exceeded three inches (1872).

The heaviest rainfall in 24 hours at Lexington was 5.45 inches, September 3, 1922. No other month has received more than 4.5 inches in 24 hours, but June has received 4.45 (1898) and July 4.0 inches (1875). The only months with daily records of less than three inches are August (2.98, 1915) and May (2.6, 1898).

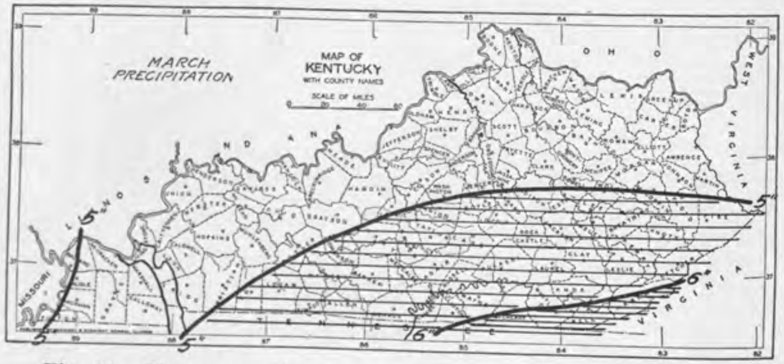


Fig. 34. The average March precipitation ranges from about 4.5 inches along the northern border to six inches at the extreme southeast. The 5-inch isopleth crosses the middle of the state.

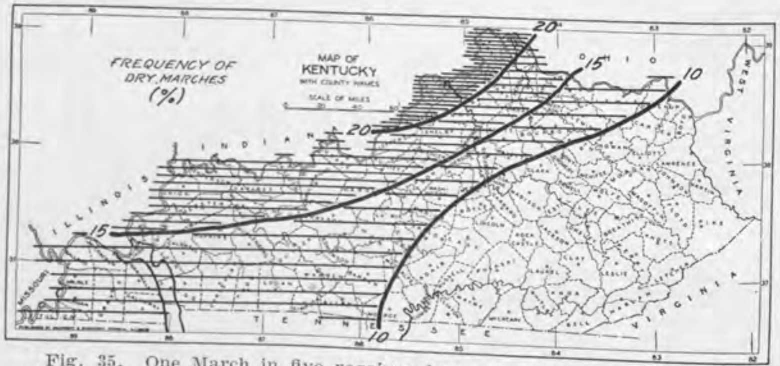


Fig. 35. One March in five receives less than half of the normal precipitation in an area in northern Kentucky while only one March in ten is that dry in the southeast third of the state.

At Evansville, Indiana, the heaviest rainfall in 24 hours has been 6.9 inches on October 5-6, 1910, but no other month has a record of over five inches, and three months (January, April and December) have records of less than three inches. The months with records of four inches are March, June, July, September.

At Cincinnati, Ohio, the record is 5.2 inches (March 12-13, 1907). Only one other month has had over four inches (October, 1910, 4.3) and five months have records of less than three inches (February, April, August, September and November).

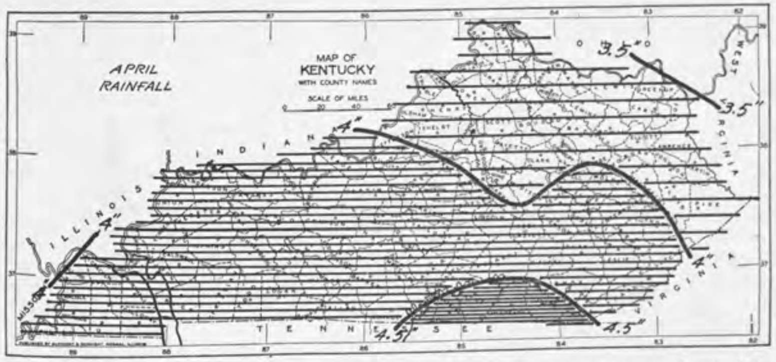


Fig. 36. The April precipitation increases on the average from the extreme northeast where 3.5 inches is received, to the south central where 4.5 inches falls.

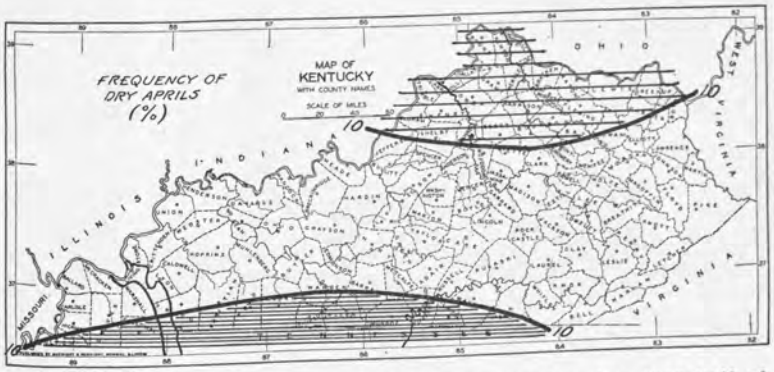


Fig. 37. One April in ten, on the average, receives less than half of the normal rainfall in northern and southern Kentucky, while in most of the state dry Aprils are less frequent.

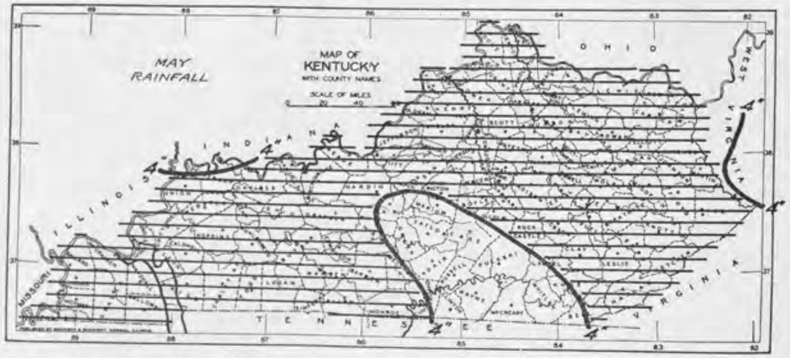


Fig. 38. All parts of the state receive slightly more than four inches of rain in May, on the average, except the south central section and small areas at the northwest and northeast which receive a little less than four inches.

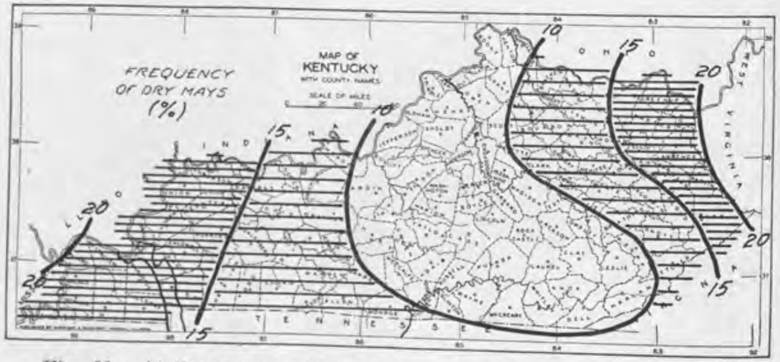


Fig. 39. At the eastern and western extremities of the state, one May in five, on the average, receives less than half of the normal rainfall while in the center of the state such dry spells are less than half as frequent.

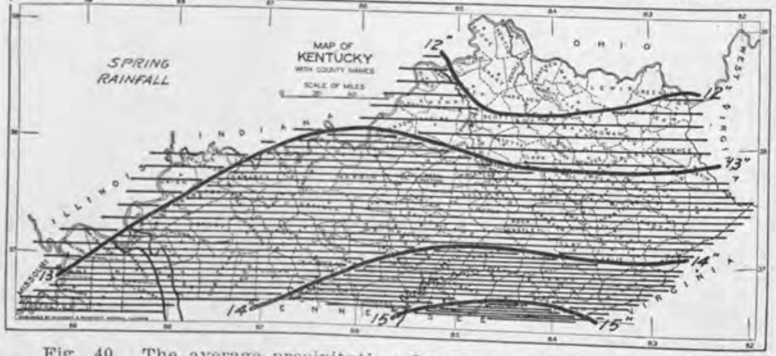


Fig. 40. The average precipitation during the spring months (March-May) ranges from slightly less than 12 inches at the north to 15 inches at the southeast.

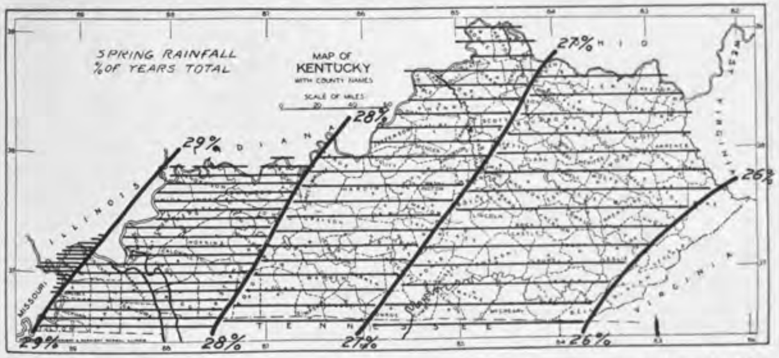


Fig. 41. Approximate percentage of annual precipitation falling in the spring quarter (March-May). Extreme western Kentucky receives about 29 per cent of the year's rainfall during spring while the extreme east receives about 26 per cent. Thus spring receives more than its proportionate share of rain.

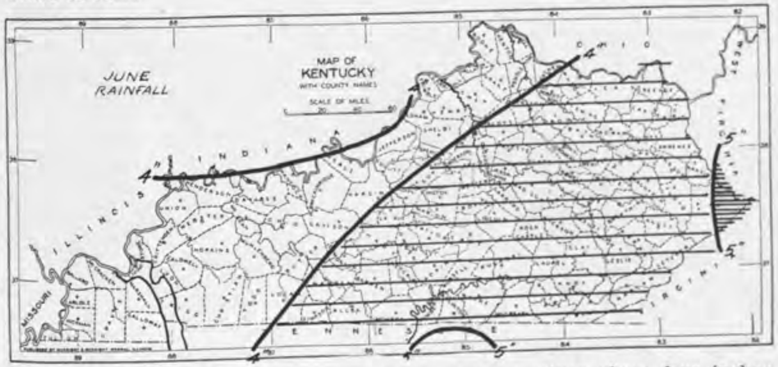


Fig. 42. On the average most of the state receives about four inches of rain in June, the northwest half receiving slightly less than four inches and the extreme eastern tip about five inches, and an area on the south central border about five inches.

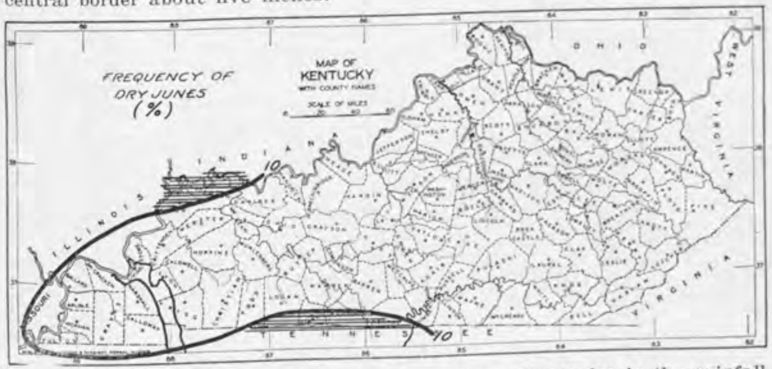


Fig. 43. Only in two tiny areas in western Kentucky is the rainfall of June as little as one-half of the normal amount as often as one June in ten, on the average. In the central counties, Junes which are that dry are rare—Lexington has had none in 55 years, and only two Junes approached it. The rainfall of June is more dependable than that of any other month in Kentucky.

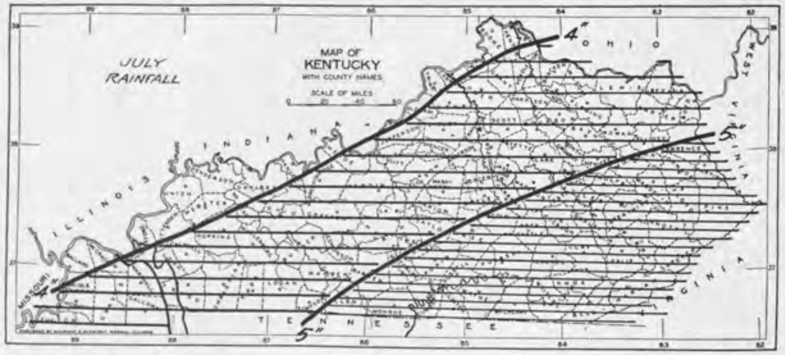


Fig. 44. On the average the northwest border of the state receives slightly less than four inches of rain in July while the southeast third receives slightly over five inches.

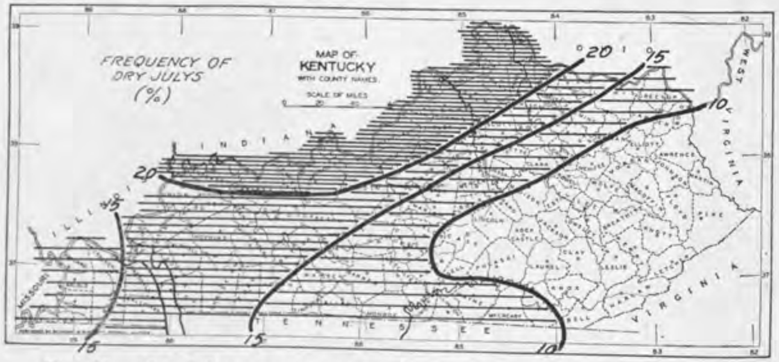


Fig. 45. Dry Julys are much more frequent than dry Junes, one in five receiving less than half of the normal rainfall in many northern counties. Only in the southeastern counties is less than one July in five this dry, on the average. There one in eight or ten are this dry.

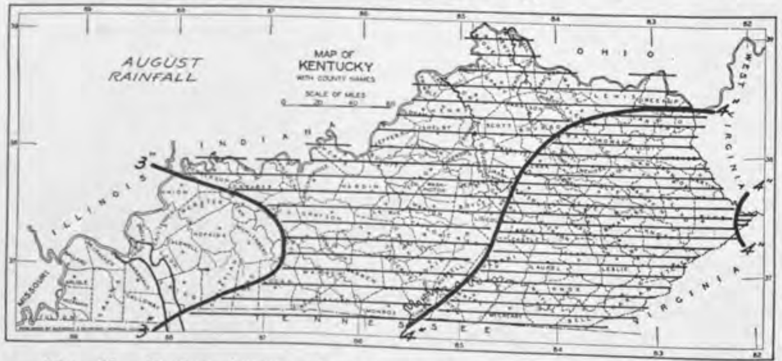


Fig. 46. During August the average rainfall is slightly less than 3 inches in the west, but from 4 to 4.5 in the eastern and southeastern parts, except at the extreme eastern section where it is slightly less than 4 inches.

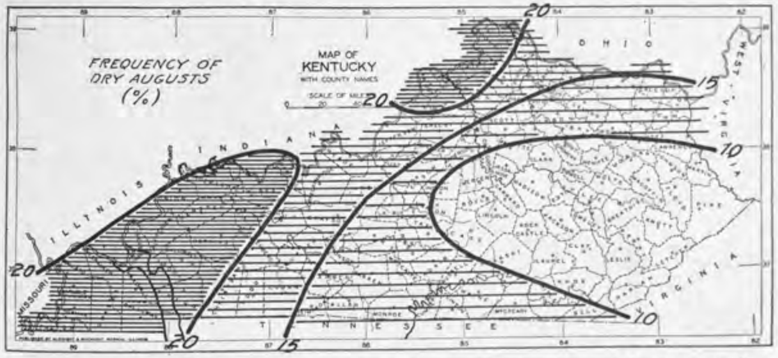


Fig. 47. In western and northern Kentucky one August in four or five on the average, receives less than half of the normal amount of rainfall, while in the southeastern counties only one in ten or twelve Augusts is so dry.

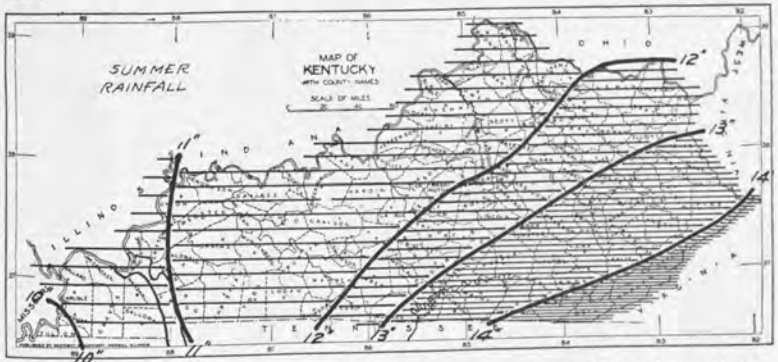


Fig. 48. On the average, the rainfall of summer (June-August) increases from 10 inches at the extreme southwest to 14 inches at the extreme southeast.

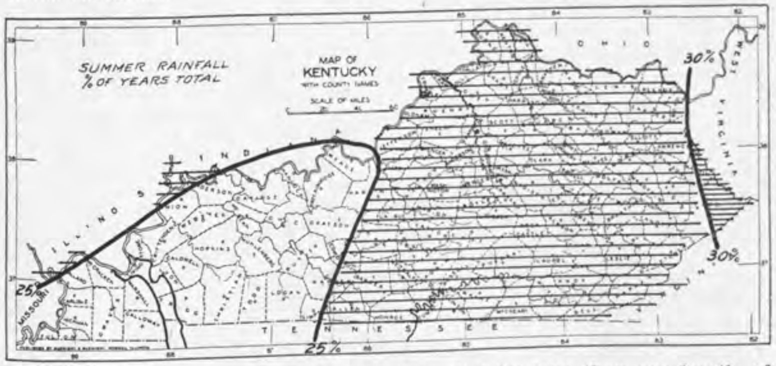


Fig. 49. Western Kentucky receives slightly less than one-fourth of the year's precipitation during the summer quarter while extreme eastern Kentucky receives 30%.

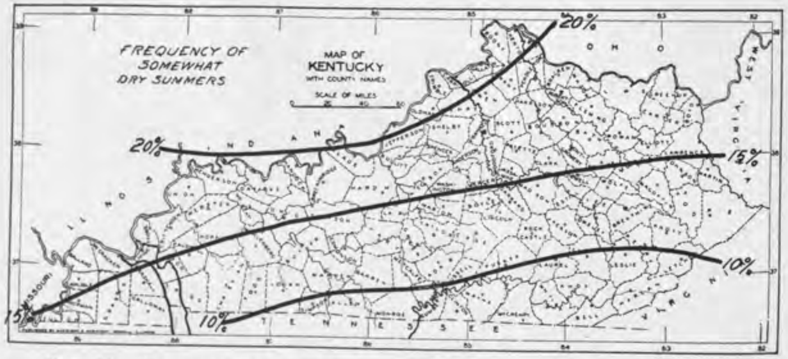


Fig. 50. Frequency of departures of 15% or more below the normal precipitation of the warmer half-year. In most of Kentucky, 10 to 20 per cent of the years receive less than 85 per cent of the normal summer rainfall.

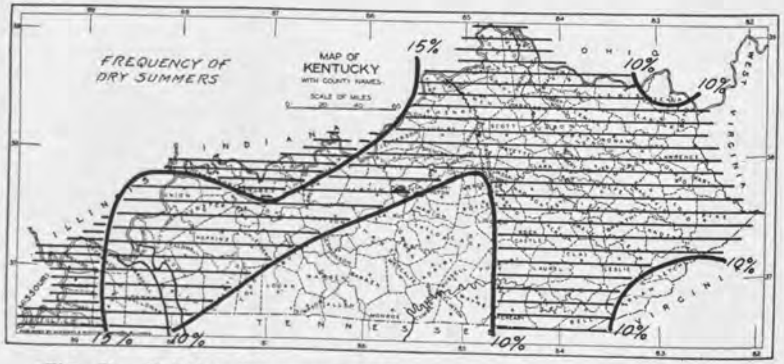


Fig. 51. Relative frequency of dry summers. In eastern and south central Kentucky, one-half year in ten, on the average, receives less than three-fourths of the normal rainfall, whereas in extreme western and northwestern Kentucky, one summer half-year in six or seven is dry to this extent.

Fig. 52. Most of the state receives somewhat less than 3 inches of rain in September, on the average; however, areas in the south central, extreme eastern and extreme northwestern receive slightly over 3 inches.

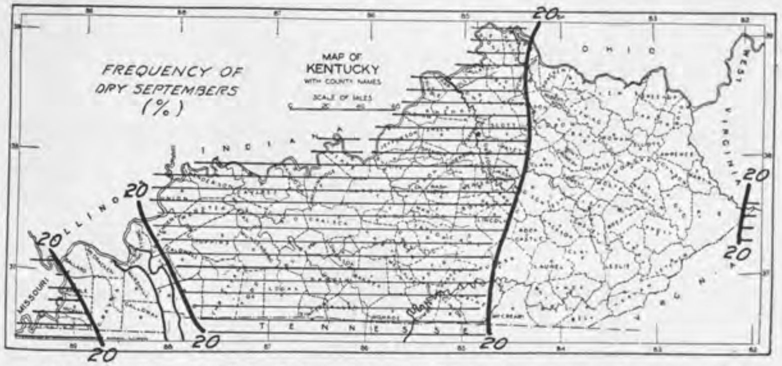


Fig. 53. The rainfall of September is distinctly erratic; for most of the state more than one-fifth of the Septembers receive less than half of the average rainfall. The eastern counties experience fewer relatively dry Septembers than do most of the western.

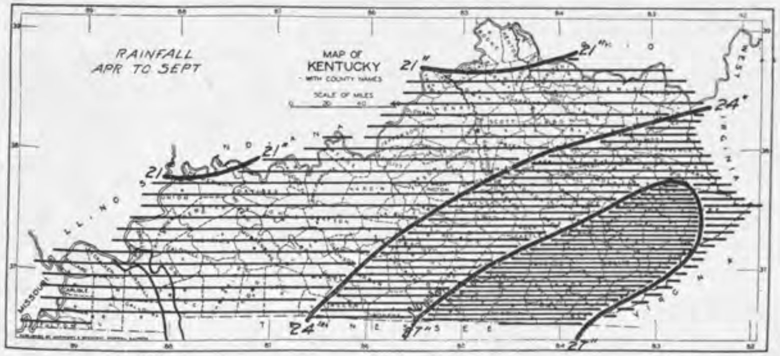


Fig. 54. The average warm season rainfall (April to September, inclusive) varies from about 21 inches at the extreme north and northwest to about 27 inches at the southeast.

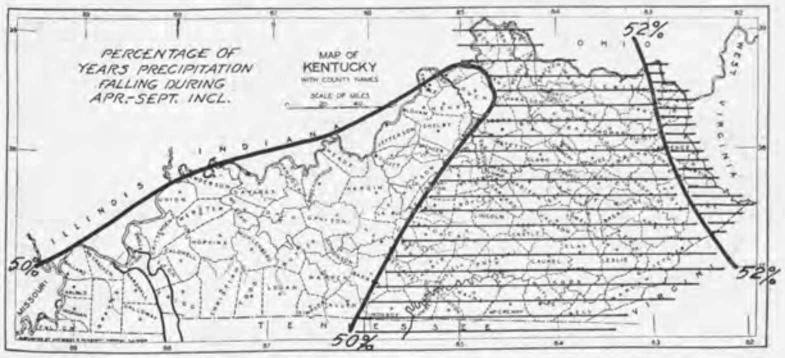


Fig. 55. Slightly less than 50 per cent of the precipitation falls between April 1 and October 1 in western Kentucky, while in the eastern part slightly more than 52 per cent falls in that half-year.

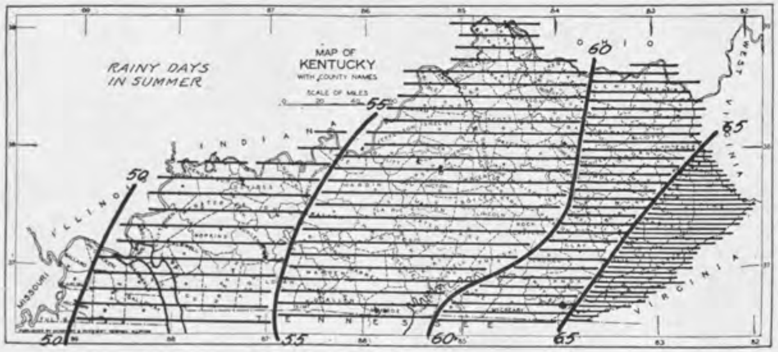


Fig. 56. Average number of days (including nights) receiving some rain (0.01 inch or more) during the summer half-year. Eastern Kentucky receives rain about 30 per cent oftener in summer than does western Kentucky, as well as about 25 per cent more in amount (Fig. 55). The further fact that a larger percentage falls during the day time (Fig. 57) makes eastern Kentucky distinctly rainier than western Kentucky in the summer half-year.

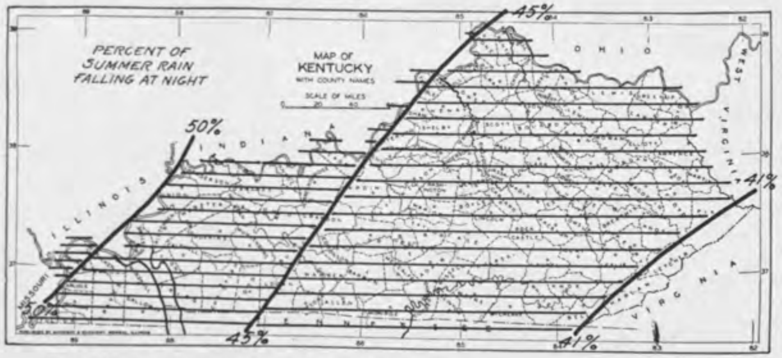


Fig. 57. Per cent of total rainfall during summer half-year which falls at night (7 p. m.-7 a. m.). At the extreme west about half falls at night; while at the east, only 41 per cent.

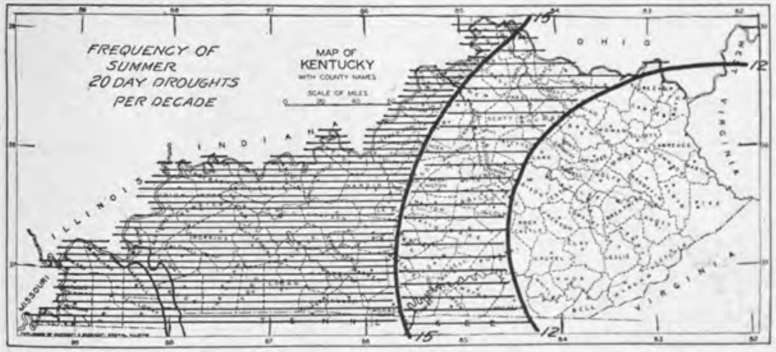


Fig. 58. In the western half of the state there are on the average in a decade about fifteen periods during which, for 20 consecutive days or more, less than ¼ inch of rain falls in 24 hours, during the season, March-September inclusive. In the eastern third, however, such droughts are somewhat less common, less than 12 occurring in a ten-year period, on the average.

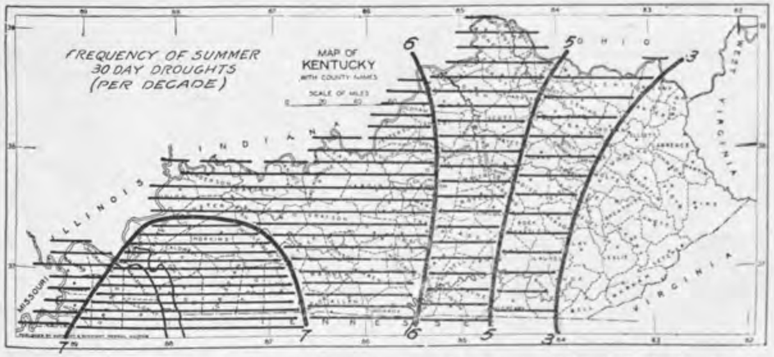


Fig. 59. Periods of 30 consecutive days or more without ¼ inch of rain in 24 hours occur during the summer half-year about seven times in a decade in western Kentucky, but only three times in eastern Kentucky.

Fig. 60. Only the southwest corner of the state normally receives as much as three inches of rainfall during October, the driest month in the year, but the rest of the state all receives an average of over 2.5 inches.

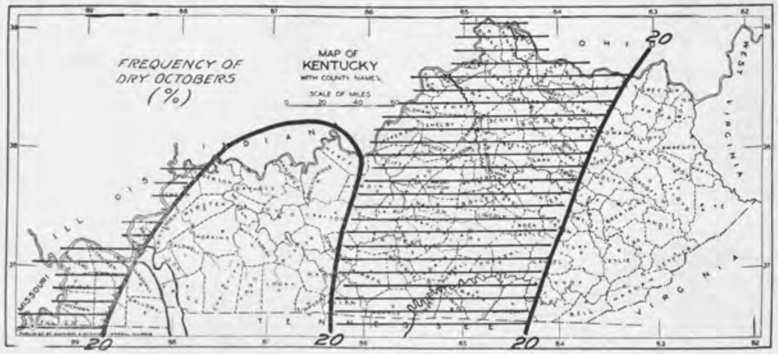


Fig. 61. The middle counties have one October in four or five, on the average, which receives less than half of the normal rainfall. The eastern and western counties (except the extreme western) have dry Octobers somewhat less frequently.

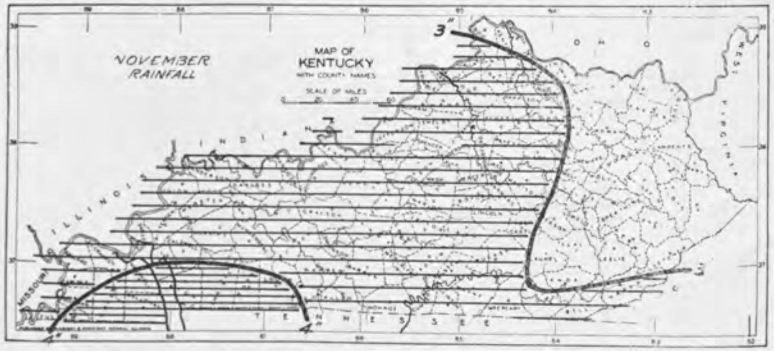


Fig. 62. During November the eastern counties are driest, receiving slightly less than 3 inches of rain, on the average, while a small area in the southwest receives over four inches.

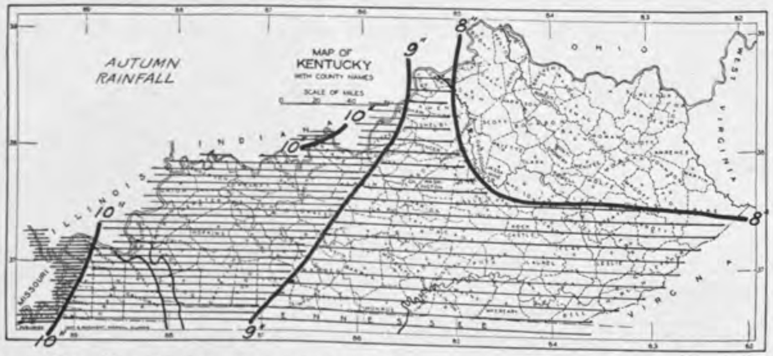


Fig. 63. On the average the fall quarter (September-November) receives slightly less than 8 inches of rainfall in the northeast, but slightly over 10 inches in the extreme west.

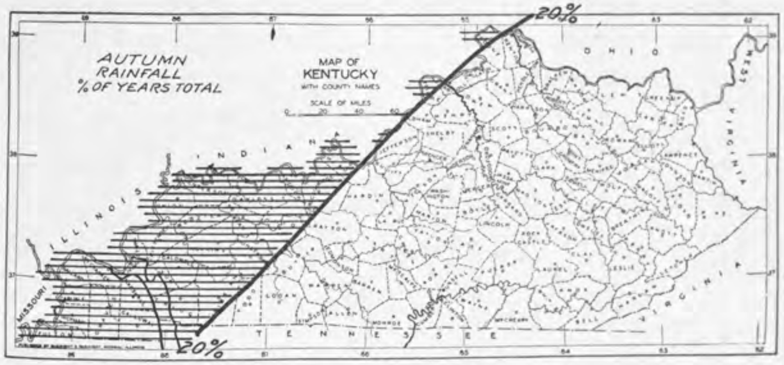


Fig. 64. Less than one fifth of the years' precipitation falls during the autumn quarter (September-November), for most of the state. The western counties receive a slightly larger percentage than the eastern.

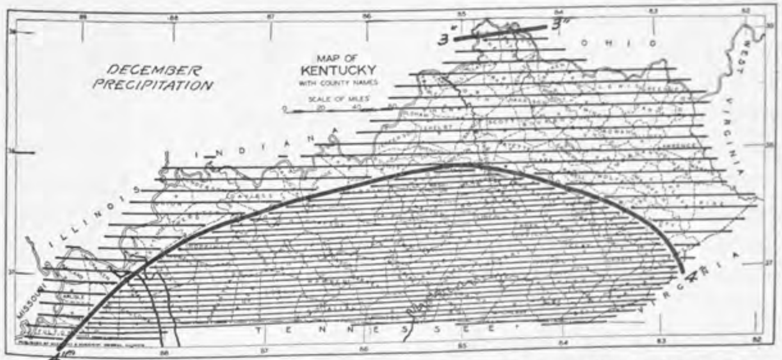


Fig. 65. Average December precipitation. Most of Kentucky receives about 4 inches of precipitation in December, the amount increasing from 3 inches at the extreme north to nearly 4.5 inches at the central south.

Temperature and Wheat Yields

Moderately cool temperatures are favorable for the vegetative growth of small grains. When moderately cool and moist weather occurs during the vegetative growth of wheat, for example, each favorably located young plant spreads, and the field

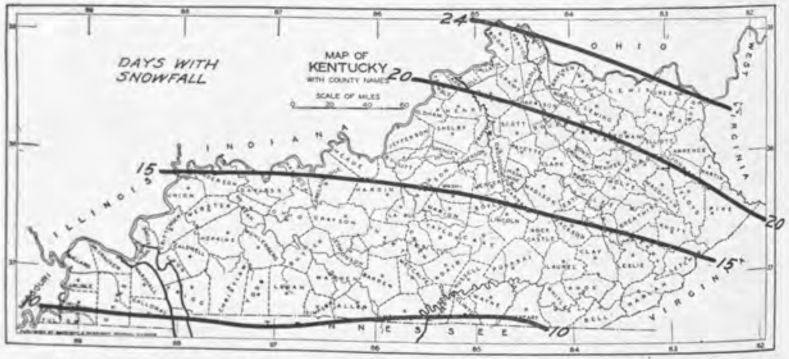


Fig. 66. Snow falls upon about 10 days each year along the southern margin of the state, and upon about 24 days at the northeast margin. The first snowfall in the autumn occurs, on the average, about November 8 at the extreme northeast, about November 16, in the central counties and about November 24 at the extreme southwest.

may become almost a sod. Then when it is time to head out a number of stalks spring from each original plant, whereas if warm weather comes too soon, the plant has had time to spread but little, and sends up, perchance only a single "head." The moderate winter temperatures of Kentucky are favorable for the growth of winter wheat, which is a chief crop. Kentucky is located, as already remarked, near the center of the "corn and winter wheat belt." However, hot weather occasionally comes too early in spring, causing the plant to head out before it has done a great deal of stooling. This means a reduced yield.

Rainfall and Crop Yields

There is a very close relationship between the amount and distribution of rainfall and the yield of crops. Corn yields illustrate this clearly. Corn should receive at least two and one-half inches of rainfall per month during the three months of its most rapid growth. When more rain than this amount falls at the right time, the yield is much increased. For example, Mosier reports that on an experimental plot of land in Illinois,

in eight years when a total of less than seven inches of rain fell during the three months, June, July, and August, the average yield was 25 bushels per acre. In the nine years when between seven and ten inches was received during these months, the aver-

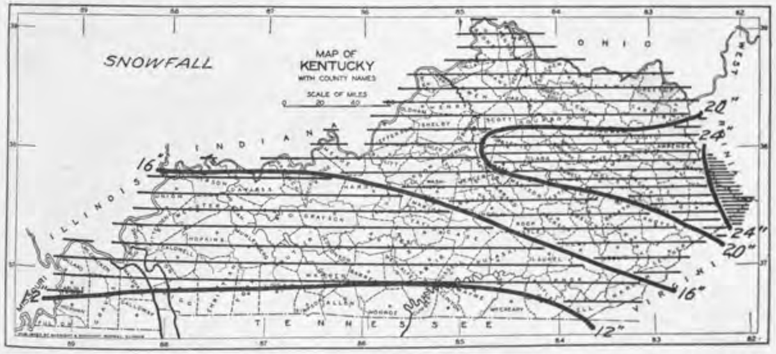


Fig. 67. Snowfall varies in amount, on the average, from about 12 inches a year at the south to twice that amount at the extreme east. Most counties receive about 16 inches.

age yield was 32 bushels per acre. In the eleven years when more than ten inches fell, the average yield was 40 bushels per acre. In the seven summers which had over 13 inches, the yield averaged 46 bushels per acre. A yield of 100 bushels of corn per acre requires about 15 inches of rain, and, of course, rich soil, favorable temperature conditions, and good care. In general, rainy weather during the last half of July and the first half of August results in a good corn yield; whereas, a drought during those weeks greatly reduces the yield.

Weather and the Growth of Tobacco

A study of the weather and the yield of tobacco in Kentucky during a twenty-year period, and for a longer period in southwestern Ohio, reported by J. Warren Smith in his Agricultural Meteorology, 1920, is interesting and valuable. The month of May should be moderately dry, so that the field may be properly prepared for the young plants. The temperature of May should be moderately cool to harden the plants. June should be moderately warm and wet to insure growth when the plants are set out. Warm weather kills cut worms, but if it is too warm and too wet, bed-rot or root-rot develops. The most favorable soil

temperature for the development of this disease is 62° to 74°. Temperatures below 59° and above 90° are unfavorable for it. June is the month having most temperatures favorable to root-rot. July rainfall and temperature should be not far from

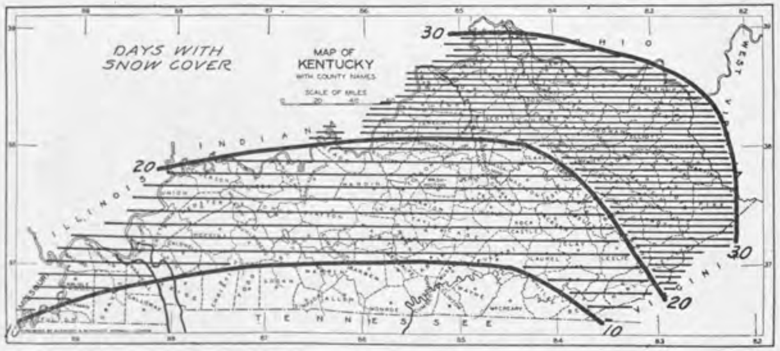


Fig. 68. Snow covers the ground fewer than 10 days during an average winter in the southern counties, but about 30 days at the extreme north and east.

normal. Rainfall slightly above normal is better than dry weather, but excessive rainfall interferes with cultivation. If dry weather prevails during July, it is advantageous that the temperatures be not excessive, as tobacco (and other crops) suffer less from drought during cool spells than during hot. August should have considerable rainfall, somewhat more than normal. Warm wet weather is favorable to a rapid growth of the tops, but also to the development of rust, which is dangerous. Hot and dry weather in August is very detrimental; cool and dry weather is less unfavorable. During seasons when the rainfall is somewhat above normal, temperatures also somewhat above normal are favorable, but in seasons having droughts, the best yields are obtained when the summer is somewhat cooler than normal. As tobacco is very sensitive to frost, late spring frosts or early autumn frosts are highly detrimental. In Kentucky, however, they seldom do much damage, as the period between the last killing frost of spring and the first one in the fall is much more than the three or four months required for the development of tobacco.

Frequency of Weather Types

A study of the weather types of Cincinnati, just across the Ohio River from extreme northern Kentucky, and at Nashville, Tennessee, thirty miles south of western Kentucky, has been

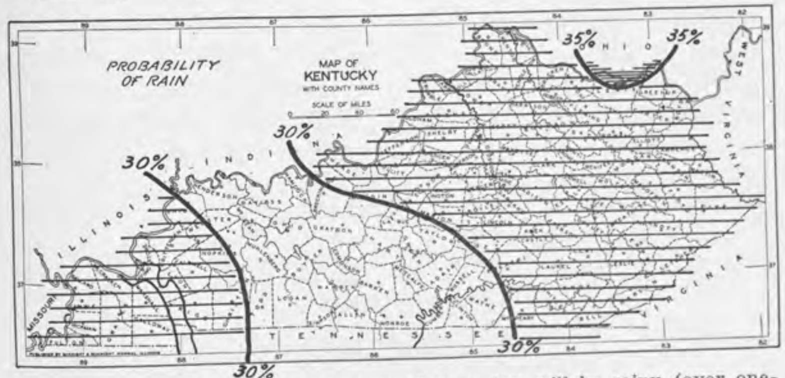


Fig. 69. The probability that any future day will be rainy (over one-half inch of rainfall) is thirty per cent in west central Kentucky, and somewhat greater in the western and eastern counties.

made by G. F. Howe (M. W. R., Oct. 1925). These stations indicate what may be expected in most of Kentucky.

During the summer months (June, July, August) 81% of the days are hot at Cincinnati and 97 per cent are hot (average above 68°) at Nashville; none are cool (average below 50°); about two-thirds of the days are clear (Cincinnati, 65%; Nashville, 67%). Only one day each summer on the average is windy at Cincinnati, but about four are windy at Nashville (wind of over 25 miles per hour). Rain falls on nearly a third of the days (32%), in both places. At Cincinnati fifteen per cent are moderate (50-68°), fair and quiet, and at Nashville, two per cent.

During the winter months (December, January, February) four per cent of the days are moderate at Cincinnati and eighteen per cent at Nashville; fifty per cent are cool at Cincinnati and fifty-nine per cent at Nashville, and forty-five per cent are cold (32°) at Cincinnati, and twenty-two at Nashville. The per cent of clear weather is almost as great as in summer, 63% at Cincinnati and 64% at Nashville (in contrast with 65% and 67% for summer). Windiness is much more frequent in winter than in summer, five per cent of the days have a 25-mile wind for

at least five minutes at Cincinnati and thirteen per cent at Nashville. Rainy days are frequent, 24 per cent of the winter days being so classed at Cincinnati and 29 per cent at Nashville. Nearly fifteen per cent of the winter days at Cincinnati receive some snowfall, but only six per cent of those at Nashville. Cold, snowy, windy days are more frequent at Nashville than farther north at Cincinnati, (3 vs. 1.8), because snow falls as far south as Nashville chiefly only on cold, windy days. Cold quiet snowy days occur three times as frequently at Cincinnati as at Nash-

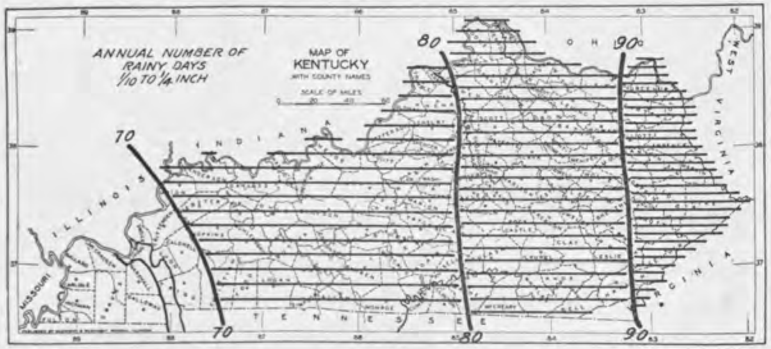


Fig. 70. The western counties have almost 70 days a year on which from one-tenth to one-fourth inch of rain falls, while the eastern counties have about 90 such days.

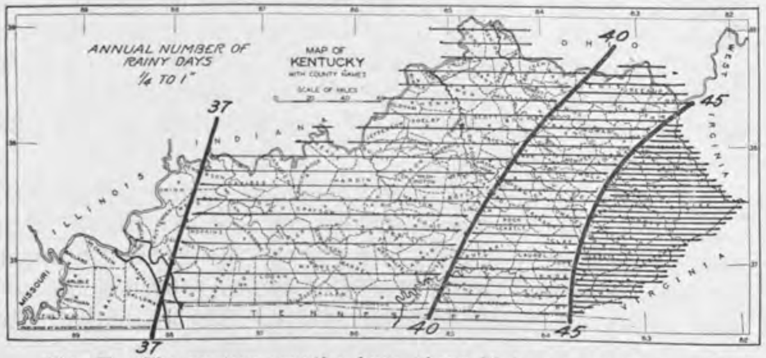


Fig. 71. The western counties have about 37 days a year upon which one-fourth to one inch of rain falls, while the eastern counties have about 45 such days. On about two days a year two inches of rain falls. Such heavy downpours are somewhat more frequent in the southwestern half of the state than in the northeastern. Rainfall of an inch an hour occurs about twice a year, also somewhat more frequent in western Kentucky than in eastern Kentucky.

ville (10 to 3), and cold, fair and quiet days over twice as frequently (31 vs. 14).

Tornadoes

On the average a tornado occurs in Kentucky yearly, killing on the average, more than ten persons. The following tabulated facts concerning Kentucky taken from a table showing corresponding data for all of the states, is from H. C. Hunter, M. W. R., Vol. 53, pp. 198-294, May, 1925:

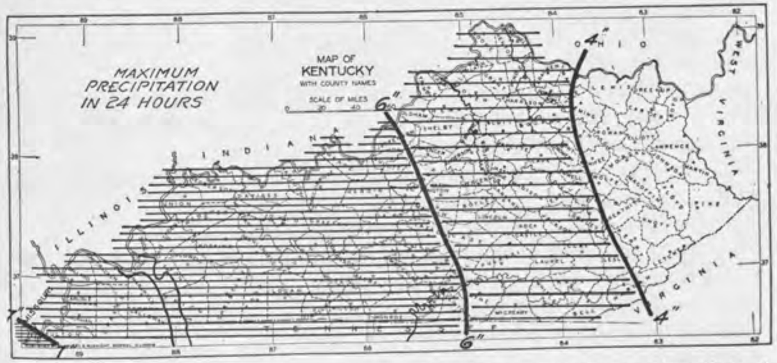


Fig. 72. In eastern Kentucky the heaviest rainfalls are less than 4 inches per 24 hours while in western Kentucky over six inches have been recorded; seven inches at the extreme southwest. Excessive rainfalls at Louisville, Lexington, Evansville, and Cincinnati are mentioned elsewhere (p. 122, 123).

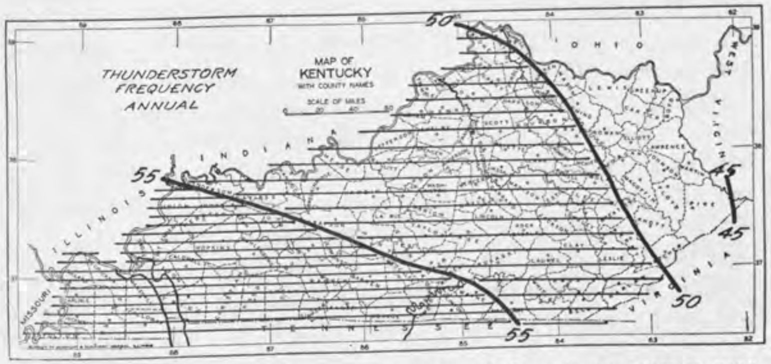


Fig. 73. Thunderstorms occur on about 55 days in an average year, in the extreme western counties and in somewhat fewer than 50 days in the eastern counties. Hail falls, however, on only one or two days in an average summer, slightly more frequently towards the west. On the average, more than 20 people are killed by lightning each year in Kentucky, a larger number in proportion to area than in states to the south or west.

Number of tornadoes during eight years (1916-1923) (six of these originated in Kentucky)	8	
Most tornadoes in a year	4	(in 1917)
Number of years with fatal tornadoes	1	
Number of years with tornadoes, not fatal	3	
Number of years with no tornadoes	4	
Loss of life by tornadoes in the eight years	75	
Loss of life by other windstorms	34	
Greatest loss in a year	75	(in 1917)
Number of tornadoes fatal to one or more persons	2	
Number of tornadoes fatal to ten or more persons	2	
Number of tornadoes not fatal	6	
Average loss of life per tornado	8	
Average loss of life per fatal tornado	37.5	
Property loss per tornado during the eight years	$2,080,000	
Property loss from other winds	$3,891,000	
Number of tornadoes causing a loss of $100,000 or more	1	
Greatest loss in a year in the eight years	$2,000,000	(in 1917)
Tornadoes recorded during the years 1874-1881	5	
Tornadoes recorded during the years 1889-1897	12	
Tornadoes recorded during the years 1916-1923	8	
Total tornadoes for the twenty-five years	25	
Total loss of life for 17 years	198	
Average loss of life per tornado	9.9	
Average loss of life per year	11.6	
Aggregate reported property loss, 1889-1897	$2,933,000	
Aggregate reported property loss, 1916-1923	$2,080,000	

Two especially disastrous tornadoes are the one at Louisville, March 27, 1890, and the one in Graves County, southwestern Kentucky on May 27, 1917. The Louisville tornado killed 106 persons (76 in Louisville) and did property damage estimated at $3,500,000, of which $2,500,000 loss occurred in Louisville. The Graves County tornado killed 70 persons, injured 370, and did damage estimated at $2,000,000. In 1925, according to J. L. Kendall, who has made a special study of tornadoes, six fatal tornadoes occurred in Kentucky: three on March 18, and two on October 16 and one on December 4. One of those on March 18 passed northeast from Tennessee to Adair County, central Kentucky, killing 12 persons in Kentucky, and injuring 60. The second one on that day caused about $850,000 damage, injured about 40 people, but killed only two persons. This tornado travelled from Marion to Bourbon counties in central Kentucky. The other tornado on this day injured about 50, killing

3. It crossed Jefferson County and ended in Oldham County. The October tornado travelled about 150 miles, from Warren County to Estill County. Only one person was killed, but about 44 were injured, and property damage estimated at $250,000 oc-

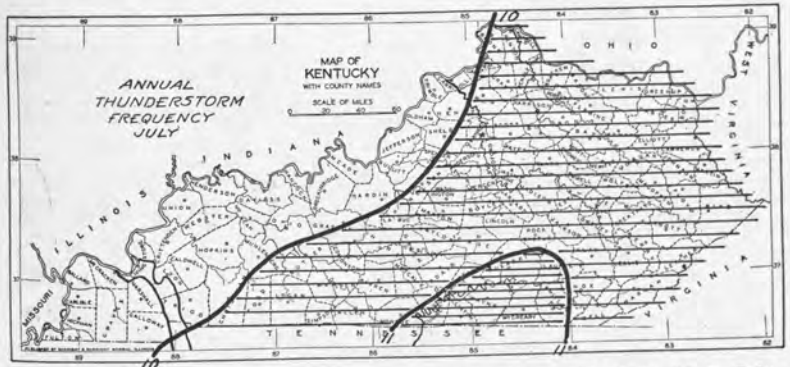


Fig. 74. About 10 thunderstorms occur in June and about 11 in July, on the average. However, they are somewhat more frequent in the south central part of the state than in the northwestern. In January, the month with fewest thunderstorms they are most frequent in the western counties, about one occuring annually.

curred. The December tornado crossed parts of Calloway, Marshall, Livingston, Lyon and Caldwell counties. It was especially destructive in Marshall County, killing two persons. The total damage is estimated at $75,000. Tornadoes were exceptionally numerous in 1925 in Kentucky. Kentucky has fewer tornadoes than states to the west and no more than the adjoining states to the north and south. The eastern part of the state is the least likely to be hit.

Changes of Climate

There is wide interest in changes of climate. That changes have occurred is abundantly proven. Most of Ohio, Indiana, Illinois, and a bit of extreme northern Kentucky were covered by a great sheet of glacial ice relatively recently, as the geologist measures time. Furthermore, at an earlier time, coral-forming polyps thrived in Kentucky, and much farther north. The falls of the Ohio River at Louisville are over a coral reef. At present, coral-forming animals do not live where the water is ever colder than 68° F. The average temperature of Kentucky is now almost 58°, which is not very far below 68°, but the cold winters

of the present make our climate very different from that which must have prevailed when the coral reefs were formed, unless the coral-forming animals have changed greatly. That the polyps have changed greatly is rendered improbable not only

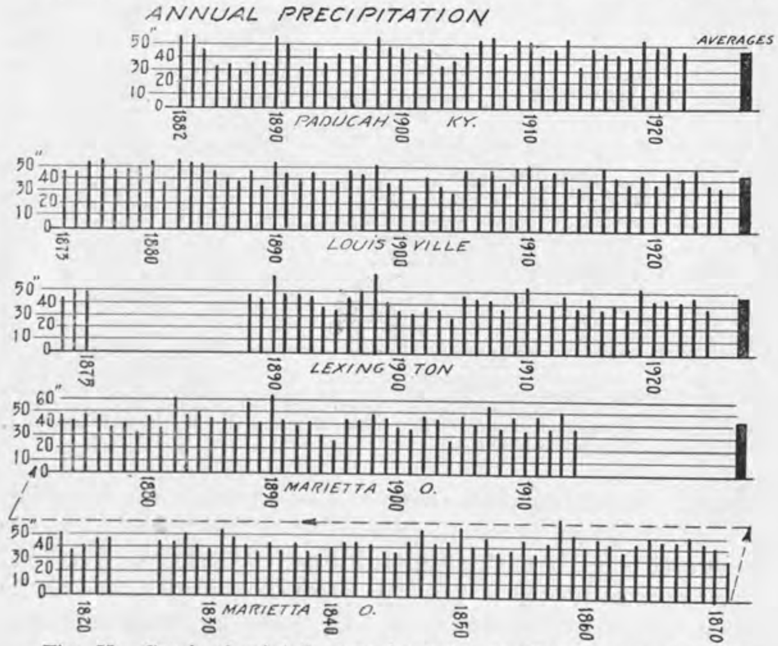


Fig. 75. Graph of rainfall, year by year, at Paducah, western Kentucky.
Fig. 76. Graph of rainfall, year by year, at Louisville, north central Kentucky.
Fig. 77. Graph of rainfall, year by year, at Lexington, central Kentucky.
Fig. 78. Graph of rainfall, year by year, at Marietta, Ohio, near northeast Kentucky.

by the lack of evidence of a change in their requirements, but by much other evidence. Many other animals and many plants now limited to tropical or subtropical regions formerly lived together in what are now cool regions. It is altogether unlikely that all this assemblage should have been changed in the same way. Indisputable evidence of past change of climate is found also in the great layers of coal discovered in the constantly frozen polar regions, in areas where now practically no plants grow. Great salt deposits, as those near Syracuse, New York, Saginaw Bay, Michigan, and Salina, Kansas, indicate the areas

now humid were once arid, just as the presence of petrified forests in the desert of Arizona and great ruins in places now deserted in North Africa and southwest Asia suggest that areas now arid were once not so dry.

These changes were not in one direction. The earth is not cooling off and drying up. This is shown by the discovery of extensive glacial deposits near the margin of the tropics in very early times, geologically, and vast deposits of desert materials, such as gypsum and salt, also very early in the earth's history.

The proof that profound changes of climate have occurred appears to lend support to the popular belief that there have been conspicuous changes in the local climate during the memory of the old inhabitants. Many an old man feels quite sure that the climate today is quite different from what it was when he was a boy.

Although it is proven that there have been great changes of climate during the millions of years of the earth's history, there is abundant evidence also that the irregularities observed during the lifetime of an individual are merely cyclic changes. A year, or a period of a few years is wetter or drier, colder or warmer than the average, and then the next group is "normal" or opposite. Whenever a long, carefully kept record, such as is now available for many Weather Bureau stations, is divided into two, and the first half compared with the last half, it is seen that there has been no apreciable change in the period. For example, the rainfall or temperature of the first half of Louisville's 53-year record averages almost exactly what it does for the second half. And this is to be expected, when it is realized that the period since the glaciers melted away from southern Ohio was tens of thousands of years ago, and yet so recent, geologically, that the temperature of Kentucky today differs only say 20° on the average, from that which prevailed when the glaciers were in southern Ohio. A change of a degree in a thousand years or more, on the average, would, of course, be entirely imperceptible during a generation.

Hence, although climate certainly has changed, and doubtless is now changing, the changes we notice are not progressive, but instead are irregularities due to differences in the paths, speed and intensity of cyclonic disturbances, due in turn to complex changes elsewhere. No year or decade is quite like an-

other, but the changes are on either side of a mean, except for such slight progressive changes as would require generations to accumulate enough so as to be conspicuous.

Figures 75 to 78 give the rainfall year by year for certain stations in or near Kentucky. They show the type of irregularity year to year that has been discussed in the previous paragraph.

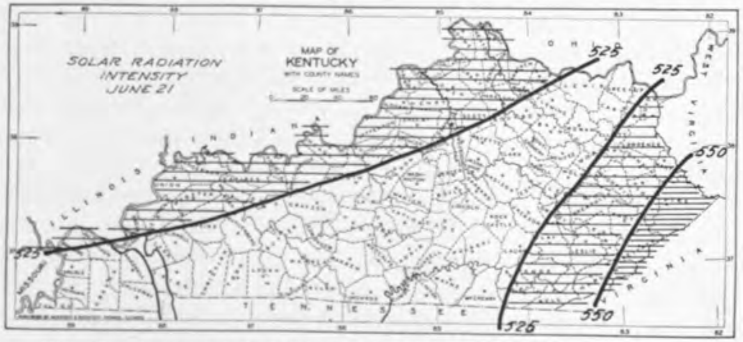


Fig. 79. Average daily totals of radiation received on a horizontal surface in gram calories per square centimeter. This amount of energy per square meter is equivalent to that required to run about 15 electric lamps (40-watt) for seven hours. The eastern tip of the state receives more energy than the rest of the state because of its greater elevation. There is less atmosphere to absorb the sun's rays.

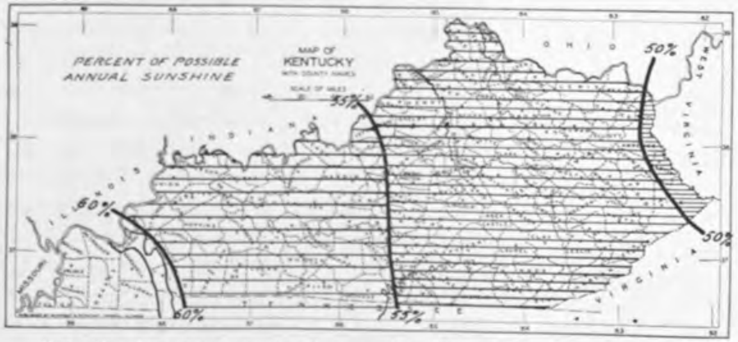


Fig. 80. The western counties receive (for the average of the year) slightly over 60 per cent of the possible sunshine while the eastern margin of the state receives slightly less than 50 per cent. The contrast between winter and summer is shown in Figs. 81 and 82.

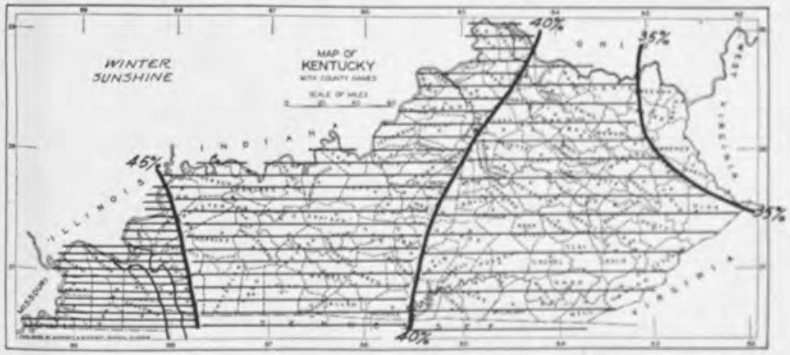


Fig. 81. On the average, about 40 per cent of the possible amount of sunshine is received during the winter months, the western tip of the state receiving about 45 per cent and the northeast about 35 per cent.

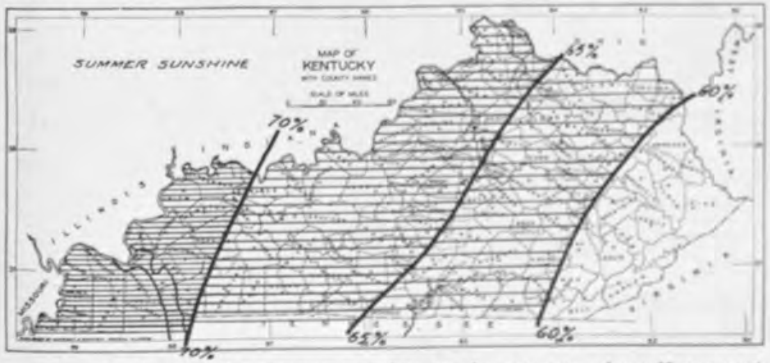


Fig. 82. During the summer months, on the average, about 65 per cent of the possible sunshine is received; the range being from less than 60 per cent in the mountains of the extreme southeast to over 70 per cent at the extreme west.

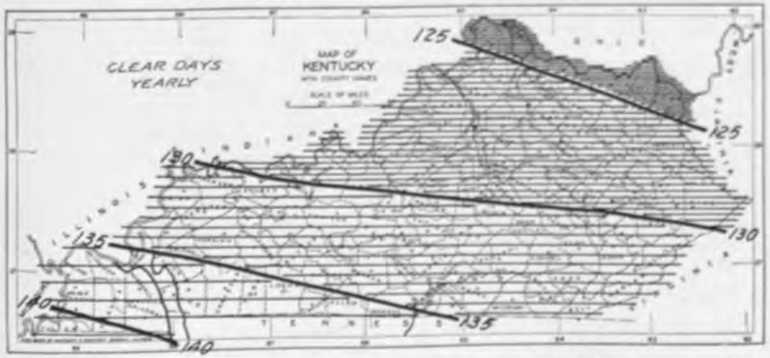


Fig. 83. On the average, 140 days a year are classed as clear in the extreme southwest, while at the opposite corner, fewer than 125 days are clear.

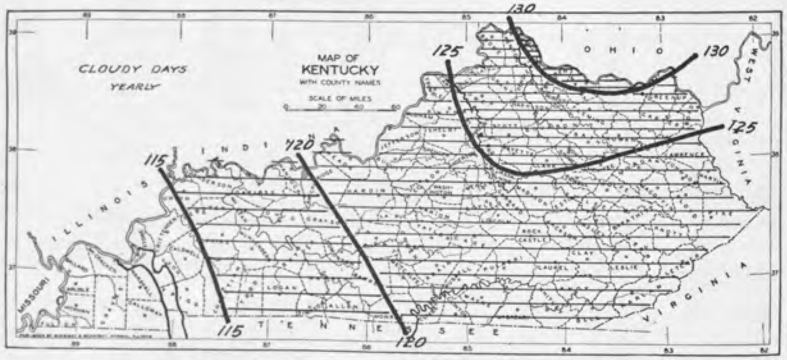


Fig. 84. Cloudiness increases towards the northeast, on the average about 115 days being classed as cloudy in the southwest and from 125-130 at the northeast. Days not classed as cloudy or clear (Fig. 83) are "partly cloudy."

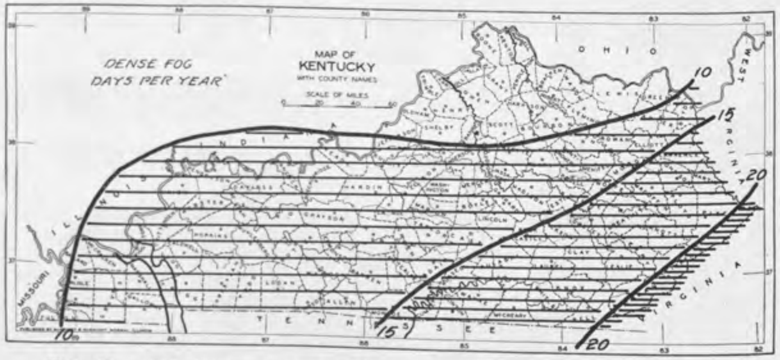


Fig. 85. Ten days a year, on the average, have dense fog at the north and extreme west, while there are 20 such fogs at the extreme southeast.

CLIMATE AND PHYSIOGRAPHY[1].

The effect of climate upon physiography is both varied and interesting. The relations, however, are involved, and to date there have been few competent attempts to discuss them. Casual

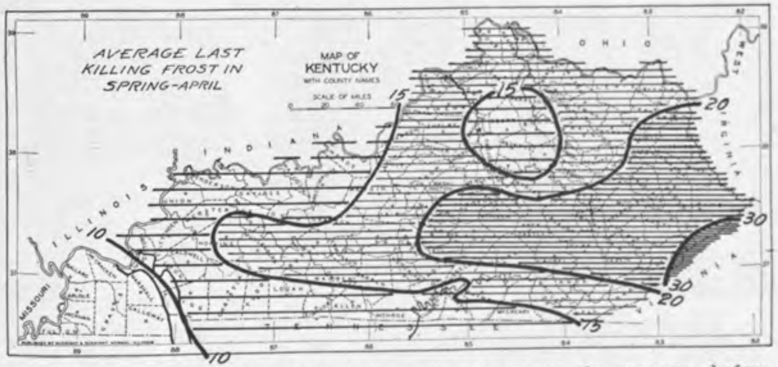


Fig. 86. The last killing frost in spring occurs on the average, before April 10 in the western counties and after April 20 in the higher eastern counties (April 30 at extreme margin). The Blue Grass region has its last frost in spring usually a few days earlier than the surrounding counties.

remarks to the effect that certain physiographic features reflect climatic conditions, are, it is true, encountered in physiographic literature, more especially in that dealing with arid regions, but are decidedly limited with respect to humid regions. Detailed discussions of this subject as relating to Kentucky by either a climatologist or a physiographer do not exist in the literature. Hence the appropriateness of a presentation at this time.

A prerequisite to a satisfactory discussion of the subject is an adequate knowledge not only of the local climate but also of the local geology and physiography. This should be augmented by extensive search in the field for evidences of the effects of the local climate upon local physiography. Since neither funds nor time adequate to such an examination were available, this discussion has been confined to a somewhat gen-

[1]Helpful suggestions concerning the discussion embracing this chapter have been received from Ellsworth Huntington, O. D. von Engeln, C. A. Malott, W. R. Jillson, E. R. Cumings, and W. N. Logan.

eral statement of the relationships. It is hoped, however that this general statement will stimulate investigation of this neglected but interesting field.

The physiography of any given region results from the action of running water, wind, change of temperature (in-

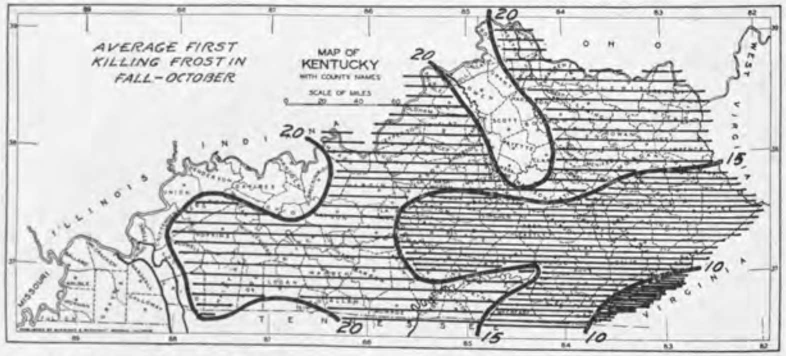


Fig. 87. The first killing frost in fall occurs, on the average, before October 15 in the higher eastern counties and after October 20 in the less elevated counties of the west, northwest and the Blue Grass region.

cluding freezing and thawing) solution, plants, animals and man; and in some places by the action of waves or ice. Also, from time to time and place to place, earth-crustal movements (folds and faults) and volcanic activity (intrusions and extrusions of lava, etc.) have had profound and far-reaching effects in the development of the physiography.

The physiography of any particular region depends chiefly upon the character and structure of the rocks, and the amount of the local relief and the stage in the erosional cycle. It is also affected, however, but the climate. The effects of the climate may be discerned by making comparisons of regions similar lithologically and in general relief but differing in climate. Major climatic differences, as between arid and humid, or cold and hot regions give rise to clearly contrasted physiographies. Lesser climatic contrasts lead to less conspicuous physiographic differences. The influence of climate upon physiography may also be studied by giving consideration to each of the climatic elements (temperature, rainfall, wind, etc.) and noting how each of these affects the physiographic processes

(weathering, erosion, transportation, deposition, solution, etc.). A sufficient knowledge of climatology and of these geologic processes allows the formulation of conclusions as to how variations in the amount of rainfall, for instance, must affect weathering and erosion, and hence how climate affects physiography.

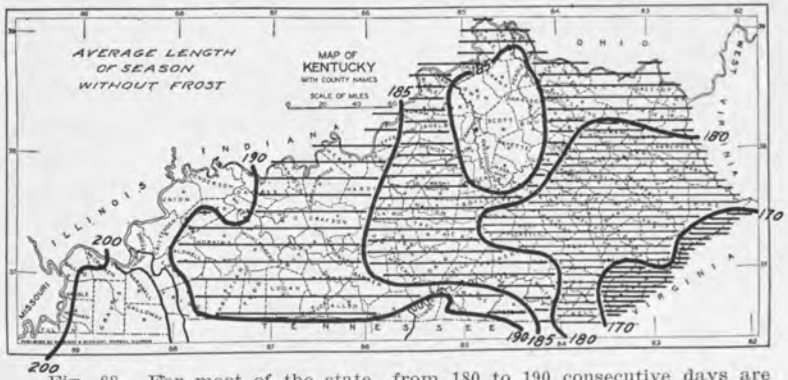


Fig. 88. For most of the state, from 180 to 190 consecutive days are free from killing frosts, on the average. At the extreme west however, there are over 200 days and in the mountainous region on the southeast border, less than 170 days. The season in the Blue Grass is distinctly longer than in the surrounding counties. The only section of the state growing cotton at all extensively is the western section with over 200 days without killing frost.

The effect of the climate upon the physiography of Kentucky might be discussed by considering how each of the several aspects of the climate must affect the different rock formations present and modify areas of varying relief and structure. Another method of approach, equally logical and more congenial to the field investigator, would be the comparison of various portions of Kentucky having a certain structure, relief, lithology, and climate with regions elsewhere differing chiefly in having a different climate. Thus deductions are made possible on how the physiography would differ if the climate alone were different from what it is.

Physiographically, most of Kentucky is a maturely dissected plateau of moderate relief (See Fig. 2.) The topography of this major portion of the area of the state owes its characteristic features chiefly to the erosive action of running water upon a variety of sedimentary rocks. These rocks have been folded to a moderate degree by ancient earth-crustal movements. The

two most conspicuous folds are: (1) those of the extreme eastern part of the state, bordering the Applalachian Mountains, and (2) the Cincinnati Anticline, in the central part of the state, upon which the famous Bluegrass region is situated.

The physiography of the major portion of the area of the state, which, as has been stated, is dominated by stream erosion, exhibits characteristics which clearly reflect the effects of the abundant rainfall of Kentucky.

Most of Kentucky is a rugged region, physiographically in the maturity stage of erosion. The little level land is largely on the flood-plains of streams. The average slope is fairly steep, but, in spite of the presence of a variety of inclined

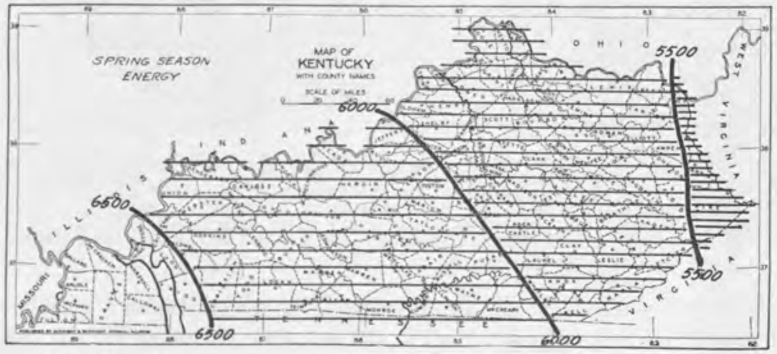


Fig. 89. The amount of energy received during the average season without killing frost; a summation of the daily temperatures above that of the dates of the last and first killing frosts. Western Kentucky has a distinct advantage over eastern Kentucky in this regard.

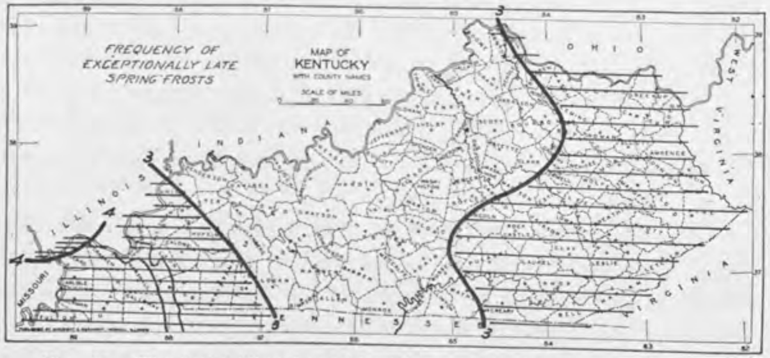


Fig. 90. The last killing frost in spring was 10 days or more later than the normal last frost in 3 of the 20 years, 1895-1914 in central Kentucky, and in 3 or 4 of these years in the eastern and western counties.

rocks, giving rise to regional cuestas, cliffs are largely restricted to the valley sides of recently rejuvenated streams, such as along the Kentucky River in the Bluegrass region.

In the semi-arid Black Hills region of the Western United States, and at various other localities in semi-arid climates, rock

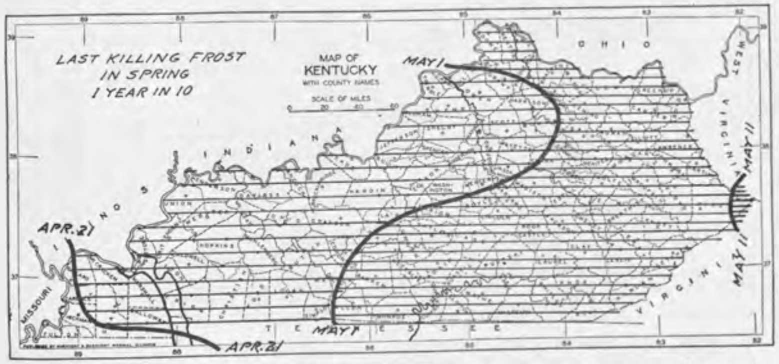


Fig. 91. The chances of frost after April 21 are as 10 to 1 at the western margin, while the eastern tip of the state has that much chance of a frost after May 11.

conditions and relief similar to those of Kentucky occur. But the physiography differs. Valleys are much farther apart, on the average, and the slopes longer and gentler, but, on the other hand, cliffs are conspicuous where rock conditions are as favorable. Fairly level land is by no means restricted to flood plains; much occurs on the divides. On some of the long slopes there are extensive rock terraces, in areas having as much relief per square mile as Kentucky has.

The climatic bases for these conspicuous physiographic contrasts are the differences, in the amount of runoff, in the weathering and in the vegetation.

In Kentucky the rainfall averages about 45 inches a year, about two-thirds of which falls during the cooler two-thirds of the year when there is not much evaporation. Hence a large amount of water, probably more than 20 inches a year, must either run away or enter the ground. Upon slopes, this means a relatively large runoff, many streams, closely spaced valleys and hence a large average angle of slope. Likewise there is abundant slope wash and active weathering.

In semi-arid eastern Wyoming, for example, about two-thirds of the 15 inches or so of annual precipitation falls during the warmer third of the year when there is much evaporation. Even in winter evaporation is fairly rapid. Probably less than three

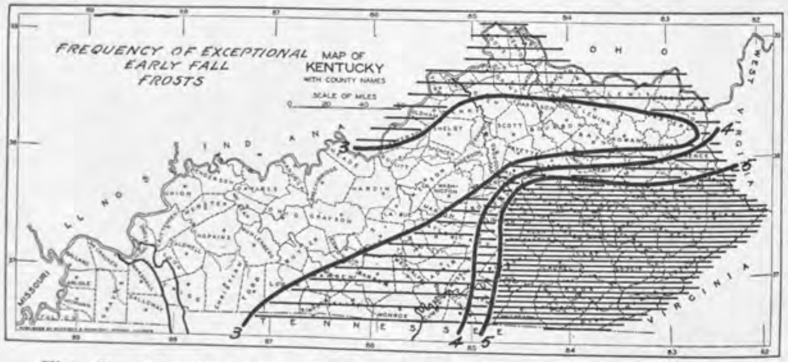


Fig. 92. The first killing frost in fall occurred 10 or more days before the normal date 3 times in the 20 years, 1895-1914 in western and northwestern Kentucky and over five times in the higher southeastern counties.

inches of water run off in a normal year, or only about one-sixth as much as in Kentucky. As erosive power depends upon volume of runoff and its velocity, both of which are far smaller, on the average, in semi-arid than in humid regions, erosional valleys in semi-arid regions are normally much farther apart than in humid regions. In arid regions, the average annual runoff is still less and hence major valleys average even farther apart than in semi-arid regions, and slopes to them average even more gentle.

The climate affects stream-erosion in yet other ways. Kentucky's winters are mild enough so that, except in short periods, the ground is not frozen, and the precipitation is in the form of rain, not snow. Streams are supplied with sediment throughout the winter. Sediment is not only an evidence of erosion, it is the tool with which streams do most of their cutting. Clear streams, such as those characteristic in winter of regions having notably colder winters than southern Indiana and hence snow-covered, are not actively eroding then.

Rainfall and temperature affect not only the percentage and amount of runoff and the annual period of erosive activity.

They also affect the character of the vegetal cover, which in turn affects erosion. Kentucky was recently nearly entirely forest-covered because the rainfall is sufficient in amount and well enough distributed throughout the year and the tempera-

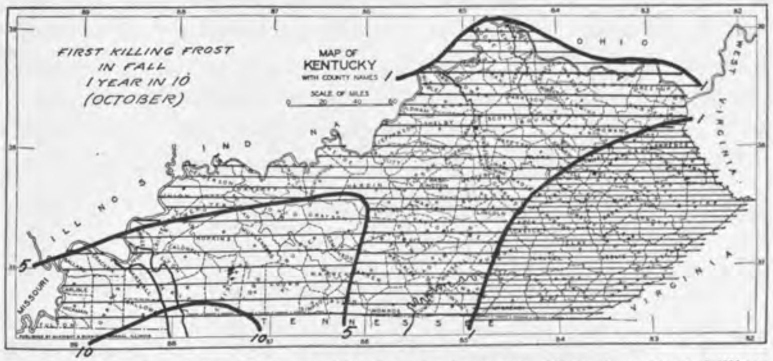


Fig. 93. In most of Kentucky the chances are 10 to 1 against killing frost occurring before about October 5. In a small area at the southwest the risk of frost before October 10 is as 1 to 10, while in the southeast highland, there is that much chance of its occurring before October 1.

ture is sufficiently high to enable trees to thrive. A forested surface erodes by slope-wash relatively slowly, on the average, because of the protective effect of roots, fallen trees and leaves. Yet down-cutting is not correspondingly retarded as roots, logs and leaves do not often seriously block streams. Hence, the local relief is increased, and therefore the average angle of slope. When the forest is removed, slope-wash can proceed rapidly, and hence soil removal and gullying are common. This accelerated erosion reduces the average angle of slope although where headward erosion (gullying) is especially rapid, it locally and temporarily steepens it.

Although the average slope in warm humid regions in maturity of erosive cycle is relatively steep, cliffs are not common except where there are special conditions such as rejuvenation or excessive solution as in karst regions. This is because slope-wash, weathering and the development of tributaries take place much more rapidly in warm humid regions than in drier ones, for reasons already mentioned. In dry regions, down-cutting is commonly much more rapid than widening, and hence streams develop steep-sided valleys, canyons if the relief is

large, or arroyas if it is small. This greater down-cutting than widening in dry regions is partly a result of the fact that much of the water in a stream in an arid region fell at some remote point, during some local shower or upon some distant mountain side. Under such conditions, slope-wash and gullying are limited to the area rained upon whereas down-cutting occurs long distances down stream. In humid regions, in contrast, the rains are much less local, at least during the cooler months when run-off is great, and hence slope-wash and gullying occur much more extensively. In other words, deepening and widening of valleys

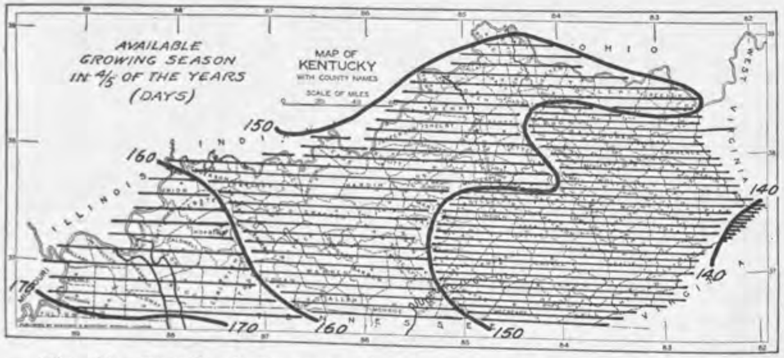


Fig. 94. Length of the season between the dates when the chance of killing frost in the spring falls to 10 per cent and date in the fall when the chance of killing frost rises to 10 per cent (Figs. 33 and 35). At the extreme east this period is about 140 days while at the extreme southwest it is 170 days. For most of the state it is between 150 and 160. Fig. 96 calculated in a different way also deals with the frost free period to be expected 4 years out of 5.

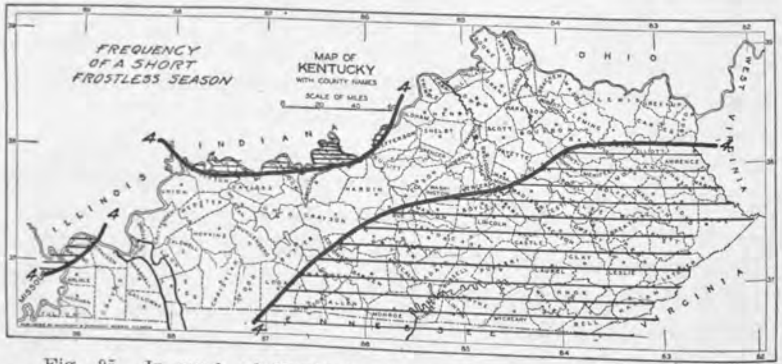


Fig. 95. In much of Kentucky the season without killing frosts was 15 days shorter than normal 3 times in the 20 years, 1895-1914. However, the southeastern counties and small areas at the northwest and west had frostless seasons of this shorter length 4 years out of the 20.

proceed together in humid regions whereas widening lags far behind deepening in arid regions, as a rule.

Also, where rocks of different resistance occur, steep-sided buttes and mesas are developed in dry regions but they are

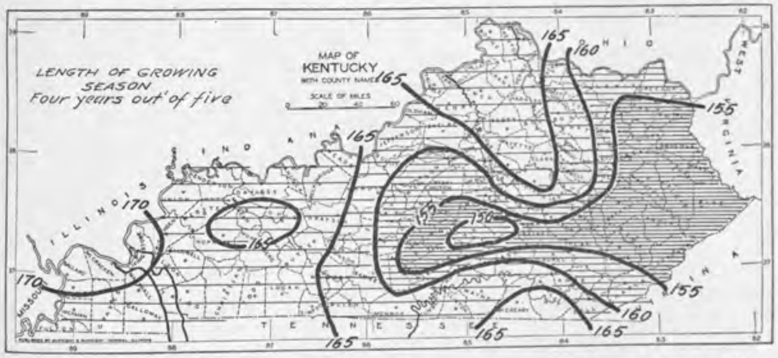


Fig. 96. The average length of the season without killing frost (Fig. 88) is distinctly longer than the season that can reasonably be expected to be free from frost because occasional seasons with exceptionally long periods without frost lengthens the average unduly. The present figure (from Walz) indicates the length of the frost free period four years out of five, on the average. It indicates that in the Blue Grass and in the western third of the state, about 165 days may be expected, but that a shorter season is to be expected in the higher areas.

rare or lacking in humid regions, where active weathering and slope-wash and the development of gullies usually soon succeed in cutting back and destroying the perpendicularity of slopes.

Although badland topography often is mentioned as characteristic of semi-arid regions, this is somewhat misleading. Badland topography develops soonest and most strikingly in humid regions upon slopes which are not protected by vegetation. Splendid examples occur at many points in the "Barrens of Kentucky." But humidity is so favorable to vegetable growth that only small areas in humid regions have the requisite slope and rock conditions to permit of the development of badlands. The small spaces between valleys also reduce the possible extension of badland areas. Consequently, in semi-arid regions where vegetal growth upon steep slopes is hindered by the inadequate rainfall and by slow soil formation, badlands are more extensively developed, in spite of erosion being less active, on the average, than in humid regions, on similarly bare, steep slopes.

While the greater part of Kentucky's physiography is characterized by stream dissection with normal valley forms and intervalley features, some rather extensive areas consist of limestone plateaus where sink-holes are common and streams are

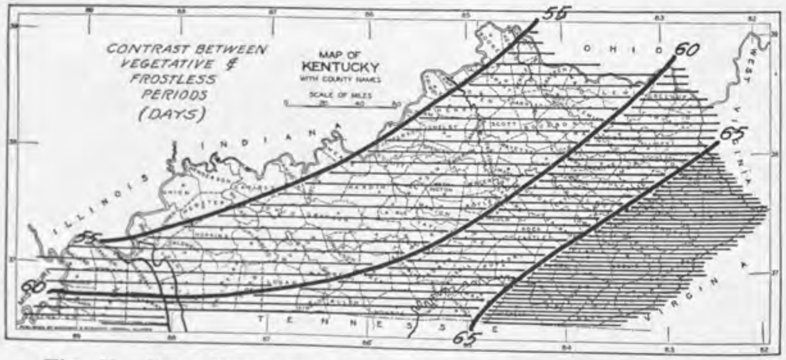


Fig. 97. Vegetation is active when the average temperature is above 43°. Frosts often occur after this average temperature is reached in the spring and before colder weather arrives in the fall. In southeastern Kentucky the period without frost is about 65 days shorter, on the average, than the period during which vegetation is active (temperature above 43°). In northwestern Kentucky, on the other hand, the contrast between vegetative and frostless periods is about 55 days.

rare.* There much of the rain enters sink-holes. After flowing a distance through underground channels, this water reappears as springs along major streams. Some of the underground channels have been so much widened by solution as to form caverns, hundreds of which have been partially explored. The most famous of these is Mammoth Cave. This limestone plateau type of region is found extensively in the Bluegrass region of North Central Kentucky and in the karst regions of West Central Kentucky. (Fig. 2.) It reflects climatic effects. It has been assumed commonly that the mere presence of limestone leads to the development of a sink-hole topography and that a karst topography is characteristic of limestone plateaus. However, examination of limestone areas in notably drier, colder or warmer climates proves that corresponding types of limestone under comparable relief conditions give rise to different sorts of

*Jillson, W. R. (American Karst Country, Pan-American Geologist, Vol. 42, 1924) estimates that there are in Kentucky 7,550 square miles of sink-hole country, and 1,450 square miles of karst topography. Kentucky is estimated to have 60,000 to 70,000 sink-holes large enough to be shown on relief maps with a 20 foot contour interval.

landscapes in different types of climate. In dry limestone regions, for example, the Black Hills region, sink-holes are relatively few and most of them are formed by the collapse of the roofs of caverns. In fairly warm moist limestone regions such as those of Kentucky, sink-holes are very common, but they are mostly of another type, having been formed by the widening of joints. Typical karst topography (areas in which the sink-holes are so large and so numerous as to occupy most of the area; sometimes indeed they actually coalesce) is not developed in dry or cold regions. Although limestone plateaus occur in all types of climates, well-developed karst regions are largely

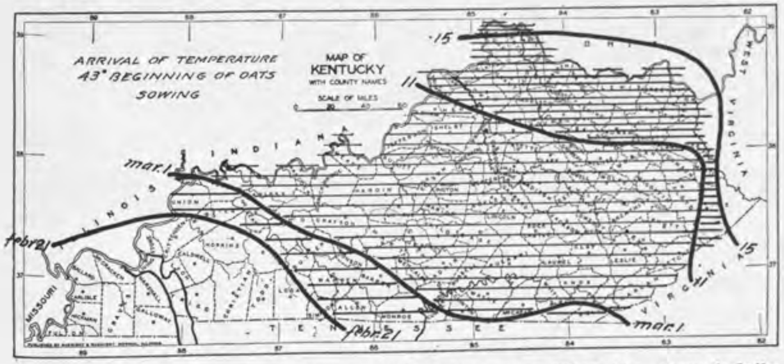


Fig. 98. The sowing of spring oats commences when the normal daily temperature rises to 43°. For southwestern Kentucky this occurs in the last week of February, while in extreme northern and eastern Kentucky, it occurs, on the average, March 15.

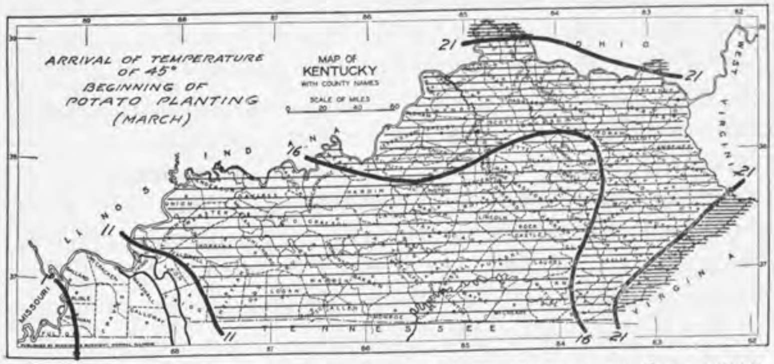


Fig. 99. The planting of early potatoes commences, on the average, during the first week of March at the extreme west, but not until the last week of March at the extreme north and southeast. These dates correspond almost exactly with those of the arrival of a daily average temperature of 45°.

limited to warm or hot regions with consideable humidity, at least during part of the year. (The rainfall and temperature conditions in the typical karst region of North Jugoslavia [formerly South Austria] are very similar to those of Kentucky).

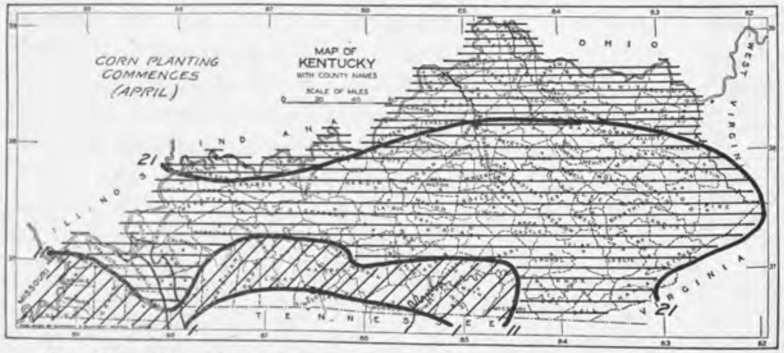


Fig. 100. Corn planting commences, for most of the state, when the daily temperature reaches about 55°, although upon the wet bottom-lands it may be delayed until the temperature reaches 57°. Corn planting begins on the average, during the first 10 days of April at the south, and in the last 10 days of April at the north and east.

In regions where the average temperature is higher than in Kentucky and the rainfall is as great or greater, as in parts of Jamaica, Haiti, Cuba, and Yucatan, sink-holes even larger than those of the karst region of Kentucky develop. Some in Jamaica examined by the writer are over 300 feet deep, and are acres in extent. In some other regions such as Greece, having somewhat less rainfall but a higher temperature than Kentucky, karst topography is also found although not so typical.

The solution of limestone, essential to the formation of sink-holes and caverns, depends upon various conditions, several of which are related to climate. Of course some limestones are purer and more readily soluble than are others, but among comparable limestones, the rate of solution depends upon (a) the amount of water passing through, (b) the amount of carbon dioxide dissolved in the water, (c) the amount of organic acids in the water, (d) the temperature. In such a rainy, humid region as Kentucky's limestone areas, large quantities of water sink into the ground and come in contact with the limestone. As vegetal growth is great in regions so moist and warm as these are

in summer, organic material is abundant on the ground, in the soil and along the partially clogged passageways through the limestone. This vegetation decays rapidly because of the warmth and moisture. Its decay yields much carbon dioxide. Hence the

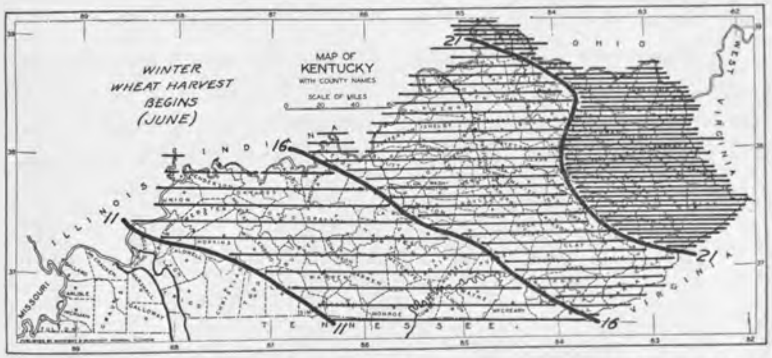


Fig. 101. The harvest of winter wheat commences, on the average, during the first 10 days of June in southwest Kentucky, and in the last 10 days in the northeast.

ground water receives large quantities of this substance which greatly increases its power to dissolve limestone. In addition to much carbon dioxide other organic acids are also taken up by the descending waters. These other acids further increase the solution action of the percoalting water. The high average temperature of Kentucky also facilitates solution when other conditions are favorable, as the rate of solution increases sharply with rise of temperature.

Kentucky's physiography is characterized not alone by the presence of certain topographic types but also by the absence of others. The rareness of cliffs, except along the numerous recently rejuvenated valleys, has been discussed. Mention should also be made of the absence of lakes, marshes, sand dunes and other manifestations of wind work.

Most of the world's lakes are results of recent glaciation. Regions not far to the north of Kentucky have many lakes because they were strongly glaciated. Kentucky's climate, however, was warm enough during the glacial period to melt the glacial ice about as rapidly as the front advanced upon the border areas of the state. The edge of the glacier accordingly

was prevented from entering into Kentucky, except for a relatively short time and for a comparatively short distance. The few shallow depressions that were formed in Kentucky by the glacier during its brief advance into the state were soon destroyed by the rapid down-cutting of their outlets associated with the large run-off resulting from the abundant rainfall.

Except in that it brings the rain, the wind is a physiographic influence of minor importance in Kentucky because of the completeness and density of the plant cover. This vegetative growth both reduces wind velocities at ground level and

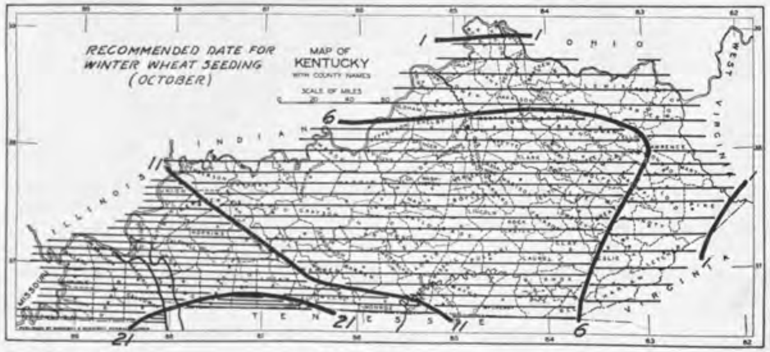


Fig. 102. The recommended date for seeding winter wheat varies from October 1 at the extreme east and north to about October 20 at the southwest. In recommending seeding at these dates, the United States Department of Agriculture has taken into consideration not only the temperature and rainfall favorable for wheat but also the reproduction of the Hessian Fly, which varies with weather conditions. Wheat seeded at the indicated dates is less likely to be injured by the Hessian Fly than wheat seeded earlier or later.

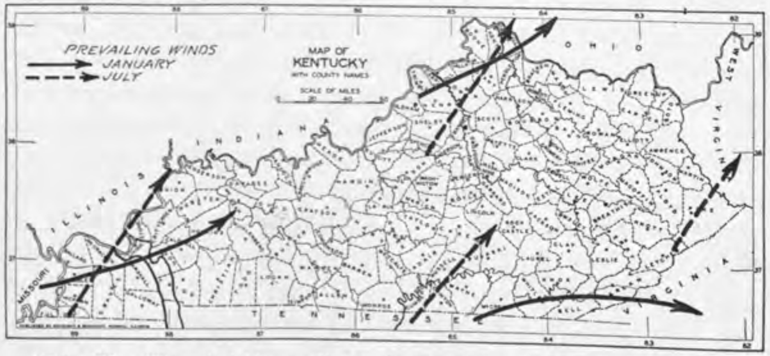


Fig. 103. The wind blows oftener from a south westerly direction than from any other direction in Kentucky; this is especially true for July. In January, however, in southwestern Kentucky, westerly winds predominate.

the availability of materials, such as sand, which the wind can transport. Sand dunes, like lakes, are lacking in Kentucky.

A special feature of the landscape, and hence of the physiography, is the percentage of rock-exposure. In Kentucky

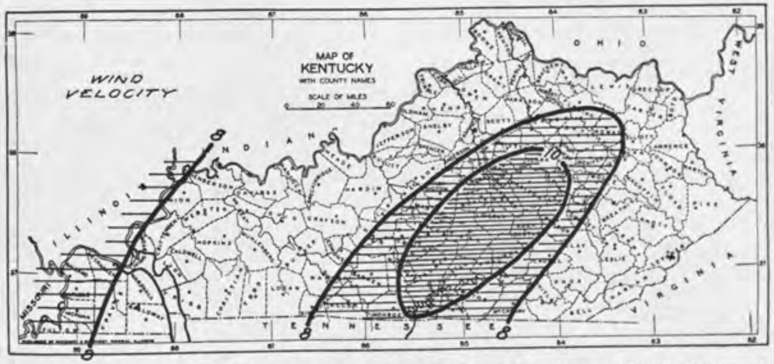


Fig. 104. The average wind velocity is about 8 miles per hour for most of Kentucky. In the central part of the state, however, the average is somewhat over 10 miles per hour. Maximum velocities of 60 miles per hour or more have been recorded in each month of the year, except July and October, at Lexington and in those months the record is 58 miles and 50 miles. The extreme record is 72 miles, August 6, 1918. At Louisville, all months have recorded winds over 50 miles, 7 months of over 60, 2 months of over 70 and the record is 74 miles per hour, May 24, 1915.

relatively little bare rock is exposed. To be sure there are conspicuous exposures along some of the gorge-like valleys and at some other special sites, but only a small part of the total area of the state has bed rock exposed. This is related to the great activity of weathering, and the rapidity of soil formation due to the fairly warm moist climate, and to the luxuriant growth of vegetation which results therefrom. In arid and in cold climates, on the other hand, a large part of the steeper slopes is bare rock because soil formation and the growth of vegetation are slow.

It is evident, therefore, that many effects of the climate can be discerned in Kentucky's physiography. If the climate were changed, various physiographic conditions would gradually be altered perceptibly.

Kentucky's climate has not always been as it now is. It must have been appreciably different during the glacial epochs, when much of the region north of Kentucky was ice-covered Detailed study might reveal local effects of the differences in

stream erosion and solutions under those conditions. Differences in wind work are revealed by the presence of some rather considerable and widespread loess deposits in western Kentucky. The winds sweeping over the ice were not interfered with by

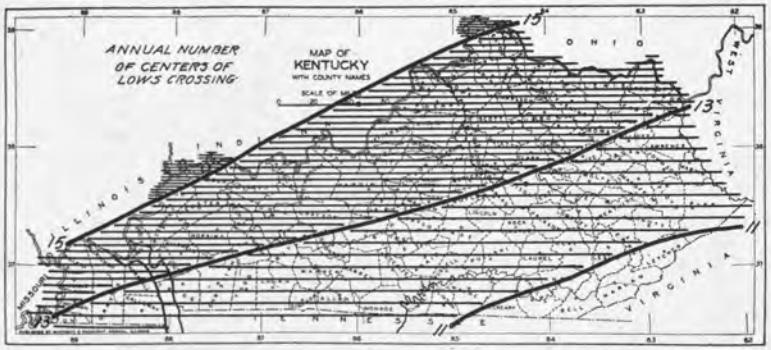


Fig. 105. According to Kullmer, about 11 centers of cyclonic disturbances cross southeast Kentucky each year on the average, while about 15 cross northern and northwestern tips. This difference means that northern and northwestern Kentucky have more frequent changes of weather than southeastern Kentucky has. Frequent changes of weather from day to day are believed to be intellectually stimulating.

vegetation and were stronger for other reasons as well, and their transporting power was greater. Also the growth of vegetation on the river-flooded plains was less rapid than now because of lower temperatures. For that reason as well as others, there was more material available for wind transportation, and the wind picked up enough fine sand and dust and transported enough of it far enough to form distinctive deposits of wind-borne materials (loess).

The recent period of glaciation, a climatic phenomenon, had various direct effects on Kentucky's physiography. Before the glacial period, the Ohio River did not exist as a major stream. Instead there were several north-flowing streams. When the ice advanced, these streams were dammed and narrow lakes were formed in their valleys south of the ice front. When the water rose high enough, it overflowed the divides towards the west, gradually developing the present westward flowing Ohio River. The large amount of drainage escaping along the Ohio River gave it great erosive power and enabled it to cut to a lower level than the several smaller northward flowing streams entering it

had been able to attain. Thus they were rejuvenated and have entrenched their valleys. One of the conspicuous physical features of much of Kentucky is the result of this entrenchment. The rivers flow, characteristically in much of Kentucky, in deep V-shaped valleys, greatly deepened since the glacial period, in direct response to conditions resulting from glaciation, a climatic event. There are numerous fine entrenched meanders and high level cut-offs along these entrenched valleys.

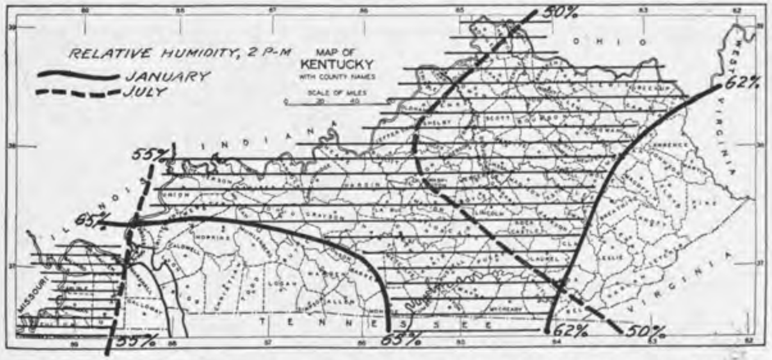


Fig. 106. On the average the air contains slightly more than half as much moisture as it can hold at 2 p. m. in July, the eastern counties being slightly drier. In January it contains from about 62 per cent to 66 per cent, the eastern counties again being the drier. In April at 2 p. m., the relative humidity is about 45 per cent and in October about 50 per cent. In April and October also the eastern counties are a little drier than the western.

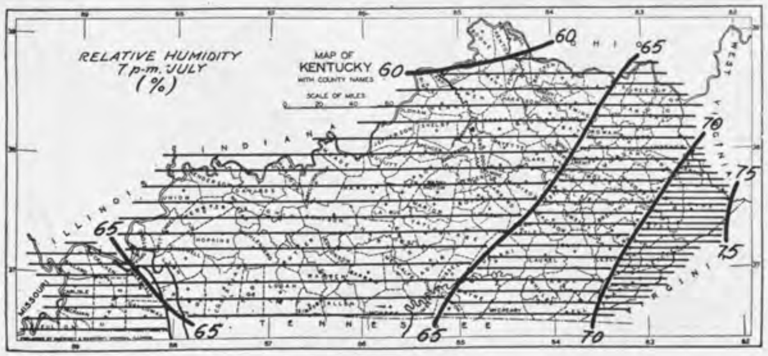


Fig. 107. The air contains about two-thirds as much moisture as it can hold at 7 p. m. in July, on the average. The most humid part of the state at this hour is the eastern counties—over 70 per cent; and the least humid portion is the northern counties—less than 60 per cent. In January, the 7 p. m. humidity ranges from seventy per cent along the southern border to 74 per cent at the extreme north. In April the range is between 55 per cent (at the south central) to 60 at the extreme west, north and east.

Summary: Conclusions reached include: The number of valleys and hence the average slope, in regions of corresponding relief, tend to increase with rainfall, especially with run-off. The percentage of fairly level land decreases correspondingly and is limited increasingly to the flood-plains of streams, in regions of corresponding maturity of erosion. Cliffs, on the other hand, are less common under corresponding rock and relief conditions in humid than in drier regions. Where limestones of similar character and topographic relations occur, sink-holes in warm

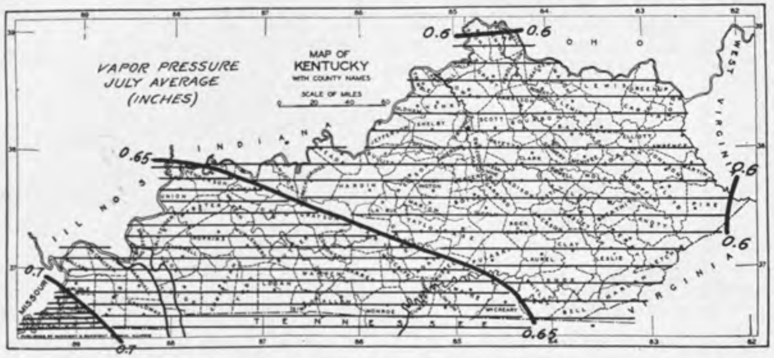


Fig. 108. In July, on the average, the air contains moisture enough to yield a layer of water about two-thirds of an inch deep if it were all precipitated. The amount increases from 0.6 inch at the extreme east and north to 0.7 inch at the extreme southwest. In January, the air is so much cooler that it contains less than a third as much moisture as in July, the range being from 0.16 inch at the north to 0.18 inch at the south.

Fig. 109. During the warmer hours of July, the dryness of the air reduces the temperature as we feel it notably. On the average there is a difference of about 14° between the wet bulb and the dry bulb temperatures at such times. The contrast is least at the extreme east—about 12°, and greatest in the west central counties—over 14°. In other words, in the warmest hours, on the average, the air does not feel as warm as it does when the air is more moist, and yet warm.

humid regions are chiefly widened joints, but in semi-arid regions are chiefly due to the collapse of cavern roofs and are comparatively rare. Dunes require certain conditions seldom found in humid climates. Most lakes are the results of glaciation. Warmth and aridity were unfavorable to glaciation and hence lakes are rare in such regions. Kentucky, therefore, located for long geological periods in a moist, humid environment in east central North America, presents a type of physiography clearly reflecting Kentucky's climate.

BIBLIOGRAPHY

Baker, O. E., Brooks, C. F., A Graphic Summary of Seasonal Work on Farm Crops, Yearbook, U. S. Dept. of Agriculture, 1917.

Brooks, C. F., Why the Weather. New York, 1924.

Brooks, C. E. P., Climate Through the Ages. London, 1926.

Cox and Armington, The Weather and Climate of Chicago. Chicago, 1914.

Davis, D. H., Geography of the Jackson Purchase, Western Kentucky. Ky. Geol. Survey, Series VI., Frankfort, 1923.

Davis, D. H., Geography of the Mountains of Kentucky. Ibid., 1924.

Davis, W. M., Elementary Meteorology, Boston, 1894.

Henry, A. J., Climatology of the United States, Bulletin of U. S. Weather Bureau, 1904.

Henry, Kincer, and Others, Weather and Agriculture, Yearbook, Dept. of Agriculture, 1924. Washington, 1925.

Humphreys, W. J., Physics of the Air. Baltimore, 1920.

Hunter, H. C., Tornadoes of the United States, 1916-1923. Mon. Weather Rev., Vol. 53, pp. 198-204. May, 1925.

Huntington, E., Civilization and Climate. New Haven, 1915, 1924.

Earth and Sun. New Haven, 1923.

Climatic Changes (with S. S. Visher). New Haven, 1922.

Jillson, W. R., Geologic Map of Kentucky, Ky. Geol. Survey, Series VI, 1923.

American Karst Country. Bull. Pan-American Geologist. Vol. XLII, August, 1924.

Kendall, J. L., Climatological Data for Sections 75 and 76 (Eastern and Western Kentucky), U. S. Weather Bureau, 1925.

Annual Summary for Kentucky and for Louisville.

Monthly Summary for Kentucky for March, October, and December, 1925 (tornadoes).

Kendrew, W. G., The Climates of the Continents. Oxford, 1922.

Kincer, J. B., Precipitation and Humidity Atlas of American Agriculture, Part II, Sec. A., Washington, 1922.

Temperature Charts for the United States, Mon. Weather Rev. 1922, Vol. 49, Charts 165-184. November, 1921.

Sunshine in the United States, Mon. Weather Rev., Vol. 48 (1920) pp. 12-17.

Kullmer, C. J., See Huntington, Earth and Sun.

Milham, W. I., Meteorology. New York, 1912.

Mosier, J. G., Climate of Illinois, (Agriculture Experiment Station Bulletin). Urbana, 1918.

Mordoff, R. A., The Climate of New York State (Agriculture Experiment Station Bulletin). Ithaca, 1925.

Peattie, R., The Geography of Ohio. State Survey, Columbus. 1923.

Reed, W. G., Frost and the Growing Season, Atlas of American Agriculture, Part I, Sec. 1. Washington, D. C., 1920.

Renshaw, J. H., Relief Map of the State of Kentucky. U. S. Geol. Survey, 1924.

Root, C. J., Some Outstanding Tornadoes, Mon. Weather Rev., Vol. 54, pp. 58-60, February 1926, and Kentucky extracts from an unpublished ms.

Smith, J. Warren, Agricultural Meteorology. New York, 1920.

Spencer, J. H., Our Climate (with special reference to Maryland and Delaware), U. S. Weather Bureau. Baltimore, 1924.

Visher, S. S., Climate of South Dakota, Bulletin 8, South Dakota Geological Survey. Vermillion, 1918.

Climate of Indiana, Handbook of Indiana Geology, State Survey, 1922; and Economic Geography of Indiana. New York, 1923.

Climatic Changes (with E. Huntington). New Haven, 1922.

Climatic Laws. New York, 1924.

Walz, F. J., Killing Frost and the Length of the Growing Season in Kentucky. Mon. Weather Rev., Vol. 45, pp. 348-353 (July, 1917).

The Drought of 1913, Ibid., Vol. 41, pp. 1453-1454.

Ward, R. DeC., Climate in Relation to Man. New York, 1918.

The Climates of the United States, Boston, 1925.

Wurtz, G. B., Annual Meteorological Summary for Lexington, Kentucky, 1925.

III.

GEOLOGY OF THE SOUTHERN PART OF THE DAWSON SPRINGS QUADRANGLE, KENTUCKY

By

A. H. SUTTON

Assistant Geologist
and Professor of Geology at the
University of Illinois

Illustrated with 26 Photographs, Maps and Diagrams

Contents

Illustrations

LETTER OF TRANSMITTAL

DR. W. R. JILLSON,
State Geologist,
Frankfort, Kentucky.

Dear Sir:—

I am transmitting herewith a report by Mr. A. H. Sutton on a portion of the Dawson Springs Quadrangle. The field work upon which the report has been based was carried on during the Summer of 1926, under my general supervision. After a considerable portion of the work was finished I spent a short time with Mr. Sutton looking over a few localities where he needed some assistance. The field work was limited primarily to the southern portion of the Quadrangle, where the Chester Series constitutes the surface formations, and where the fault structures are an eastward continuation from the southern portion of the Princeton Quadrangle.

In accordance with your desire, however, the accompanying geological map has been made to cover the entire Quadrangle, including the fault structure in the more northern part as mapped by Mr. A. F. Crider some years ago. The existence of faulting along the belt through Dawson Springs shown by Crider, is well established, but the true fault pattern if it were worked out in detail, doubtless would conform more nearly with that of the southern belt, rather than with the straight, nearly east-west faults shown on the map. However, the mapping of the faults which are confined to the Pennsylvanian area is a more difficult problem than the structural mapping in the Chester area.

In the Chester there is a well established succession of thin formations, all of which are rather easily recognizable, but in the Pennsylvanian the succession of recognizable beds is not sufficiently well known to render much service in the elucidation of the faulting. It is not unlikely, however, that sufficiently detailed field studies may render possible the mapping of the faults in this Pennsylvanian area in nearly or quite as satisfactory a manner as in the Chester area.

The report has been written by Mr. Sutton under my guidance and supervision, and during its preparation we have had repeated consultations concerning it.

Very truly yours,
STUART WELLER.

Chicago, Illinois, April 12th, 1927.

GEOLOGY OF THE SOUTHERN PART OF THE DAWSON SPRINGS QUADRANGLE

By A. H. SUTTON

CHAPTER I.

INTRODUCTION

LOCATION

The Dawson Springs quadrangle of the United States Geological Survey Topographic Atlas is located in the western part of Kentucky (Figure 1), and covers 15′ of latitude and 15′ of longitude lying between the parallels 37° 00′ and 37° 15′ north latitude and the meridians of 87° 30′ and 87° 45′ west longitude. It includes an area of about 240 square miles and comprises portions of Caldwell, Hopkins, Christian, and Trigg counties.

ACKNOWLEDGMENTS

The field work upon which this report is based, was carried on during the field season of 1926 by the writer with no assistance except that of Dr. Stuart Weller, who in company with the writer spent one day in the area visiting several localities and checking up on the identification of the various formations.

Only that portion of the quadrangle in which the Mississipian formations outcrop, was studied in detail. The Pennsylvanian formations were examined only where it was necessary to determine their relations to the Mississippian and to establish the Mississippian-Pennsylvanian contact, and they are mapped as undifferentiated Pennsylvanian on the Areal Geology map (Plate 1). Because of the lack of any detailed study of the Pennsylvanian formations only a general description of them is attempted in this report. For a more complete discussion of these rocks the reader is referred to the report of A. F. Crider on the Pennsylvanian of this area.[1] Examinations were made of some localities north of the Mississippian-Pennsylvanian contact in order to determine the relation of the alluvium to the Pennsylvanian and the results of these examinations are incorporated on the Areal Geology map.

The writer is indebted to Dr. Stuart Weller of the University of Chicago for aid given in the identification of the fossils

[1] A. F. Crider, Report on the Geology and Mineral Resources of the Dawson Springs Quadrangle, Kentucky Geological Survey, Series IV, Vol. II, Part 1, 1914, pp. 22-51.

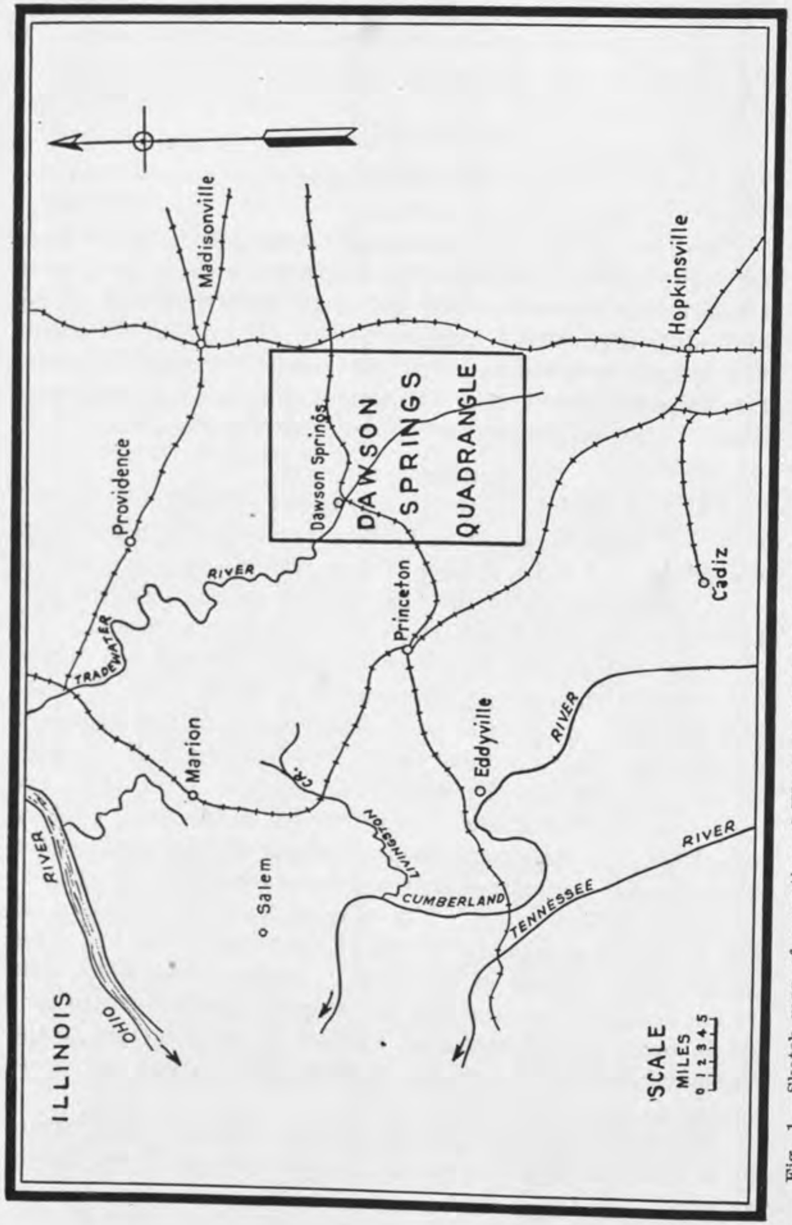


Fig. 1.—Sketch map of a portion of Western Kentucky, Illinois, and Tennessee showing the position of the Dawson Springs Quadrangle.

reported in the several lists included in this report, for assistance in the determination of some of the formations and for many valuable suggestions and criticisms during the writing of this report. In the carrying on of the work, Dr. W. R. Jillson, Director of the Kentucky Geological Survey, has done much to facilitate the investigation.

General Geologic Relations

Of the broader geologic relations of the Dawson Springs quadrangle, the following are among the most outstanding: (1) The southern boundaries of the Western Coal Basin of Kentucky and of the Pennsylvanian formations cross the quadrangle in a general east-west direction, a part of one of the more productive coal mining districts of western Kentucky being included in this quadrangle. (2) The eastward extension of the highly faulted area of western Kentucky and southeastern Illinois, with which the important fluorspar deposits of the two states are associated, is continued across the southern portion of the quadrangle.

Description of Locations

In the State of Kentucky it is more difficult to describe the exact location of specific localities than in those states where the federal land surveys have divided the land into townships and sections.

The Kentucky quadrangles, however, are divided by the 5′ lines of latitude and longitude into nine smaller sections, which may be designated as rectangles, and, for purposes of location, some nomenclature of these rectangles is convenient. In this report the rectangles have been named in terms of their position in the quadrangle. Beginning at the northeast corner and ending at the southwest corner they have been designated as follows: first, the northeast rectangle, second, the north central rectangle, third, the northwest rectangle, fourth, the west central rectangle, fifth, the central rectangle, sixth, the east central rectangle, seventh, the southeast rectangle, eighth, the south central rectangle, and ninth, the southward rectangle.

In addition to this system of subdividing the quadrangle for purposes of location, a map showing the location of the faults of the area has been prepared (Plate V). On this map

the faults are numbered and places have been located in terms of fault blocks bounded by faults of certain numbers. Finally, many points have been located with reference to certain definite topographic and cultural features such as streams, schools, churches, towns, etc.

CHAPTER II—TOPOGRAPHY

INTRODUCTION

In the topographic atlas being prepared by the United States Geological Survey, the configuration of the earth's surface is shown by means of contours on a topographic map, and such a map of the Dawson Springs quadrangle (Plate II) accompanies this report. The quadrangle is included in that physiographic province of the United States designated by Fennemann[1] as the "Western Unnamed Section of the Interior Low Plateaus" and is characterized in general as "a low, maturely dissected plateau with silt filled valleys."

Topography and Relief

After the uplift following the early Tertiary base-leveling of this region the surface of the Dawson Springs quadrangle was a low plateau, essentially plane, highest in the southern part and sloping gently to the northwest. In the course of its physiographic history the region has become greatly dissected by stream erosion and now presents an appearance of mature development with narrow divides between narrow and deep stream valleys whose slopes of varying degrees of steepness comprise the greater portion of the surface. The topography is largely controlled by the character of the underlying bed rock, although in a few places the structure appears to have been the dominating factor in the development of the surface forms.

The southern part of the quadrangle (approximately one-third) which is underlain by the Upper Mississippian formations, offers excellent examples of the effects of bed rock on topography. With few exceptions the sandstone strata are the capping formations for uplands, or occur as steep slopes and vertical cliffs; in places also, they form the beds of many of the small streams. The limestone and shale formations, on the other hand, underlie the relatively gentle slopes or terraces on

[1]N. M. Fennemann, Physiographic Provinces of the United States, Annals Assn. Amer. Geographers, Vol. VI, Pl. I, 1917.

slopes, with sandstones above and below, or they are the surface formations in the wider valleys and in the areas of rolling country. So constant is this relation that the observer can, in almost all cases, predict the kind of rock constituting the surface formation of a particular locality from an observation of the topography. However, there are exceptions to this, for in places the more massive limestone members outcrop in bluffs along the

Fig. 2. Chester Topography North of Bainbridge Church Cypress Sandstone caps the hills in the foreground while the Tar Springs covers the hills in the background.

Fig. 3.—Looking west down the valley of Dripping Springs Branch. Lowlands underlain by Menard limestone. Bluffs on either side formed by massive Palestine sandstone.

streams or cap small hills, and elsewhere sandstones underlie more gentle slopes.

This relationship of bed rock to surface form is more characteristic of the part of the quadrangle where the formations of the Chester Series outcrop than in those parts where the Pennsylvanian formations are at the surface, although here,

Fig. 4.—View of lower Chester topography north of Bainbridge Church.

too, a definite relation between underlying rock and topography can be observed. In general, the Pennsylvanian formations consist of alternating sandstones and shales, with the shales becoming quantitatively more important as the higher part of the stratigraphic column is approached. In the lower portion of the Pennsylvanian where the sandstone strata are dominant the valleys are narrow and steep-sided; where the streams pass from the sandstones to the areas underlain by shales, the valleys widen and the slopes become more gentle.

This distribution of surface formations tends to divide the quadrangle topographically into two rather distinct parts. In its southern third the divides between streams are flat topped ridges from one-fourth to three-fourths of a mile wide, the valleys are deep and narrow with precipitous sides, except where the limestones and shales are exposed at the surface in the broader valleys and in the areas of softer topography and less abrupt relief. In the northern two-thirds of the quadrangle the divides have been eroded back to narrow irregular ridges or even to a succession of hills and saddles.

Within the areas of those two types of topographic expression there are some exceptions to the characteristics which have been outlined. In the southwestern corner of the quadrangle is an area of more level land, although here, too, the relief is considerable. This area roughly includes the greatest exposures of the relatively thick Paint Creek limestone and shale formation between the rather thin Bethel and Cypress sandstones. Another area of less rugged topography is in, and north of the valley of Cany Creek where the thicker Pennsylvanian shales constitute the bed rock at the surface.

The area of greatest topographic relief or ruggedness is in the west central rectangle south of the town of Dawson Springs. This greater relief is due to the thick and massive sandstone and conglomerate beds which here make up the basal part of the Pennsylvanian formation and through which the streams have cut channels to depths of from 200 to 300 feet.

One other topographic feature worthy of mention is the peculiar widening and narrowing of the valleys of many of the streams in the southern half of the quadrangle. This situation arises from the relation of drainage lines to the hard rocks. It is most pronounced along the course of Tradewater River and several of its more important tributaries from the south. The regional dip of the rocks is to the north-northeast, bringing the beds to lower elevations in that direction. This general dip is modified in many places by the complex faulting. Where the streams cross the harder, more resistant formations such as the Chester standstones and the sandstone members of the Pennsylvanian, especially the lower conglomeratic layer, the valleys are narrow with precipitous sides. Where they emerge from these to the areas underlain by the limestones and shales of the Chester or the shales of the Pennsylvanian the valleys widen and flood plains have been developed. The flood plains are composed of rather coarse material brought down from the uplands and deposited here in time of high water, filling the valleys to depths of ten to fifteen feet. Much of this filling apparently has taken place since the cultivation of the land has been in progress.

The type of topography described above is not unique for the Dawson Springs quadrangle. It is in general agreement

with the topography existing wherever the Chester Series constitute the surface exposures, and examples of it have been described from many different regions.[2] In all of these the resistant sandstones cap the ridges and hills or form bluffs and

Fig. 5.—Characteristic Chester topography. Hills in the distance capped with Tar Springs sandstone. Looking east from a point along the Princeton Pike two and one-half miles northwest of Bainbridge Church.

steep slopes along stream courses, and the less resistant shales and limestones underlie gentle slopes, terraces, and areas of rolling country.[3]

Although the region is extensively faulted, the faulting is not conspicuously reflected in the topography. Locally some of the faults coincide with stream valleys and cross divides through saddles, but there is no outstanding topographic feature that can be taken as indicative of faulting. The lack of such characteristic features is due to the long period of erosion that the region has undergone since the deformation, which has obliterated all surface traces of the faulting. The same situation obtains throughout the faulted district of Western Kentucky, and attention has been called to it in the quadrangles to the west of the Dawson Springs.[4]

[2]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, p. 1.

[3]J. E. Lamar, Geology and Mineral Resources of the Carbondale Quadrangle, Bulletin 48, Illinois Geological Survey, 1925, pp. 16-19.

Stuart Weller and Chas. Butts, Geology of Hardin County, Illinois State Geological Survey, Bulletin 41, 1920, p. 21.

[4]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, p. 1.

The maximum relief in the Dawson Springs quadrangle is somewhat more than 400 feet. The lowest point lies below the 380 foot contour where Tradewater River flows off the area in the central part of the northwest rectangle, and the highest point, slightly above 780 feet elevation, is in the vicinity of Woods Chapel in the southwest rectangle. The maximum local relief is to be found in the same locality and along the courses of Piny and Clifty Creek, where the summits of the ridges are from 250 to 300 feet above the beds of the streams below.

Drainage

The Dawson Springs quadrangle lies almost entirely within the drainage basin of Tradewater River, which enters the quadrangle near the southeastern corner and flows in a general northwest direction, leaving it near the center of the west side of the northwest rectangle. Throughout this distance the stream follows an irregular and winding course in a valley which in places has a flood plain as much as a mile in width upon which the stream meanders. Elsewhere the valley is narrow and deep, forming an irregular winding gorge with the appearance of intrenched meanders. The gorges are present in the areas of outcrop of the hard, resistant sandstones of the Pennsylvanian and Chester formations, and the wider portions of the valley exist where the stream has sunk its channel and is now cutting laterally in the less resistant beds. The same features are characteristic of the tributaries from the south. The more important tributaries joining Tradewater River from this direction are Brushy Fork, which unites with it in the southeast rectangle; Sandlick, Camp, and Tugler Creeks in the south central rectangle; McKnight Creek, in the central rectangle, and Piny and Montgomery Creeks in the west central rectangle. Dripping Springs Branch, Whitehorn, Castleberry, and Buffalo Creeks and Cany Creek and its tributaries are the important streams draining into Tradewater River from the east.

In the southwestern part of the quadrangle the drainage is south to Cumberland River by way of Wallace Fork, Sugar Creek, and several smaller streams. Drake, Brown, and Craborchard Creeks and Pleasant Run carry some of the drainage of the eastern part of the area east to Pond River. Richland and Lick Creeks head near the northern boundary of the quadrangle and flow to the northwest in a direction more or less parallel to the course of Tradewater River. The quadrangle as a whole is well drained, except for some small marshy areas on the wider portions of the flood plain of Tradewater River.

Some examples of diverted drainage exist. Castleberry Creek formerly flowed into Tradewater River a short distance below Pooles Mill Bridge, near the northwestern corner of the southeast rectangle. It now unites with the Tradewater about one and three-fourths miles farther down stream. The situation appears to be a case of piracy, a small tributary of Tradewater River having worked headward along the course now occupied by the lower waters of Castleberry Creek succeeded in diverting the waters of the latter. Crider[5] suggests the possibility of the change in drainage being due to a small uplift of the rocks near the former mouth of Castleberry Creek, but no evidence of such recent uplift has been observed by the writer. Crider also suggests that the widening of the valley of Tradewater River between Collins Bridge and the mouth of Sandlick Creek has been due to a slight uplift in the central part of the quadrangle, but the phenomenon of alternating wide and narrow parts of the stream valleys is too common and general a feature and too definitely related to the character of the bed rock to make it necessary to suppose a special case for this portion of the valley of Tradewater River.

Another example of diverted drainage exists where the combined waters of Piny and Clifty Creeks unite with Tradewater River. The old abandoned channel of the creeks is now occupied by a marsh and the creeks flow into the river farther up stream. About one and one-half miles west of Dawson Springs a portion of the former channel of Tradewater River exists, now abandoned and converted into a marsh, completely surrounding an area of higher land. Trace Creek, which now flows into Tradewater near the western edge of the quadrangle, formerly united with it about two miles farther up stream. A small tributary of Tradewater, eroding its way headward, has succeeded in capturing the waters of the lower portion of

[5] A. F. Crider, Geology and Mineral Resources of the Dawson Springs Quadrangle, Kentucky Geological Survey, Series IV, Vol. II, Part I, 1914, p. 18.

Trace Creek, diverting the stream and causing the abandonment of the lower portion of the former channel of the creek.

CULTURE

Dawson Springs, with a populaiton of about 2,000, is the only town of important size in the quadrangle. During the last few years it has grown in size and importance because of its development as a health resort. The waters of several springs containing sulphur, iron, magnesia, and other minerals are being commercialized, resulting in a growing industry.

Crabtree, St. Charles, and Daniel Boone, three small coal mining towns east of Dawson Springs, on the Illinois Central Railroad or on railroad spurs, are the only villages within the limits of the quadrangle. A number of small country stores are scattered through the area which, because of the condition of the roads in the winter season, serve as trading centers for the rural population.

One railroad, the Illinois Central, crosses the area in a southwest-northeast direction from Princeton through Dawson Springs. Within recent years another branch of the same road has been constructed north from Dawson Springs. The Louisville & Nashville Railroad has a line between Henderson, Ky., and Nashville, Tenn., which extends north and south, just east of the quadrangle.

The wagon roads of the quadrangle in general are in a deplorable condition, and only one good road—that between Dawson Springs and Earlington, Ky.—exists in the whole area. This road, recently constructed, is surfaced with gravel and is in excellent condition. The Princeton Pike, so called, which crosses the southwestern corner of the quadrangle, is a pike in name only. From the point where it enters the quadrangle near Bainbridge Church to the crossroads two and three-fourths miles northwest of there, the road is passable most of the time. It was originally hardsurfaced, but has been allowed to deteriorate until now it is almost beyond repair. From the crossroads to the point where it leaves the quadrangle it is an ordinary dirt road, as are all the other roads of the area with the exception of the Dawson Springs-Earlington road. In the summer when these roads are dry, and in the winter when the ground

is frozen, it is possible to travel them, but after rains and in the autumn and spring it is impossible to use them except on foot or with horses.

In the southern part of the quadrangle where the divides between streams are flat-topped ridges, the roads for the most

Fig. 6—View of one of the more typical two-room houses which are still to be found in the hills of western Kentucky.

part are laid out along the tops of the ridges, descending into the valleys only where it is necessary, or they follow along the streams themselves. In the northern portion the roads commonly cross the ridges and valleys alike.

Farming is the most important pursuit of the population. Many of the farm houses are fairly good, but a great many of the people still live in primitive two or three-room log houses (Fig. 6) that are but little more than cabins. The occupants of these homes are hospitable to the highest degree and will share all they have with a stranger when they are convinced of his honesty, but are inclined to look with suspicion at first upon a new person coming into the neighborhood.

During the last decade a general exodus of the people from the farms to the city has taken place until at the present time about one-half of the farms have been abandoned and the soil of these abandoned farms is being rapidly eroded from the uplands and deposited in the valleys along the stream courses. This general abandonment of the farms has been most pronounced in the more hilly sections, where erosion is naturally most rapid, and has resulted in the removal of so much of the soil that no amount of labor or outlay of money can again bring

the land to such a condition that it can be profitably cultivated. Steps should be taken to reforest these hills, which really should never have been put into cultivation.

Although no technical study of the soil has been made, it may be said that in the lowland areas and on the slopes and

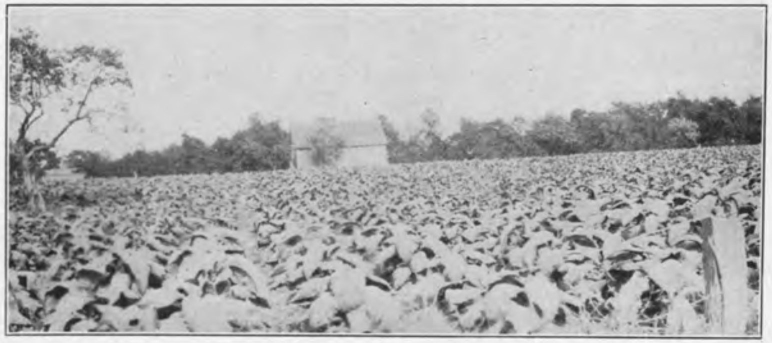


Fig. 7.—A tobacco field in one of the limestone soil areas.

terraces underlain by limestones and shales of the Chester Series the soil is fairly fertile and productive, but that of the sandstone districts is thin and relatively unfertile.

Tobacco is the principal money crop of the farmers, and under favorable conditions the yields are good in the more fertile spots (Fig. 7). During the past two years an attempt has been made to introduce cotton into this part of the state, but the success of the venture has not as yet been assured. Aside from tobacco, corn is the most important crop grown. The region offers a possibility for a combination fruit and dairy farming community when an outlet for the products is assured. In neighboring areas more favorably situated for transportation this combination has been tried with success.

Aside from farming, coal mining is the only important industry of the inhabitants of the Dawson Springs area. A number of mines are in operation, producing a good quality of coal, the most important of these coal mining centers being at Crabtree, St. Charles, and Daniel Boone.

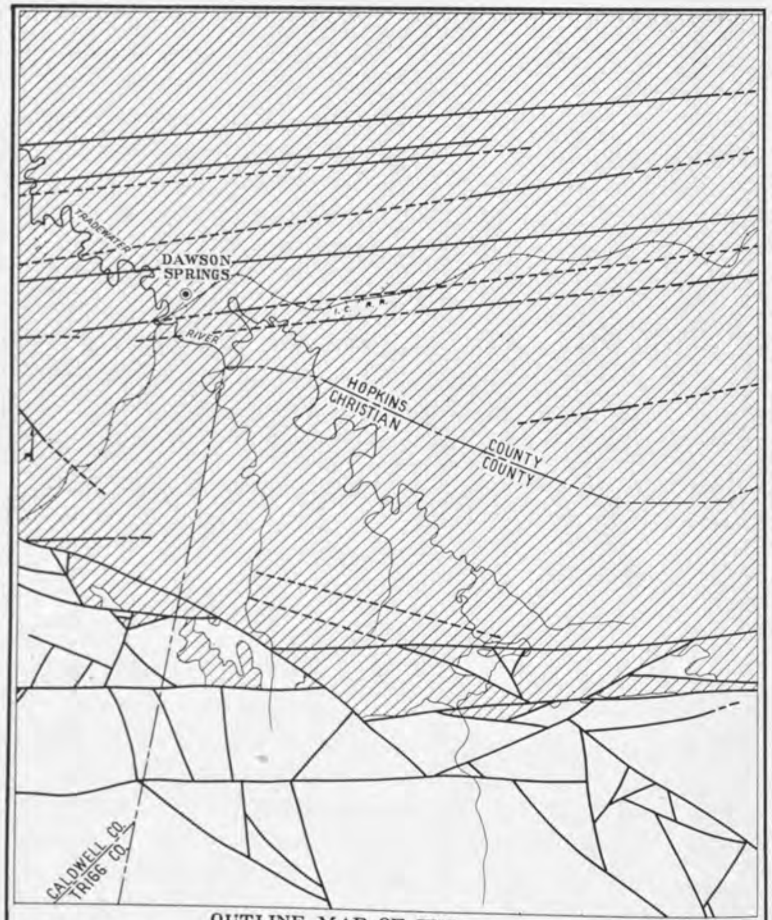
Economic Resources

Coal is the most valuable of the mineral resources of the area, and a more complete account of the coal and coal mining will be found in the report of A. F. Crider.[6]

The area has been prospected for oil and gas in a number of localities, but with no favorable results. Unfortunately no logs of the wells drilled have been available. The prospects for oil development do not appear favorable in the southern part of the quadrangle because of the complex faulting which the region has undergone, but farther north in the area where the Pennsylvanian formations are exposed, chances for obtaining oil are perhaps less remote.

Several of the limestone formations are potential sources of building stone, and in a limited number of places as a source of supply of lime, especially some of the oolitic members of the Paint Creek Limestone. Mention has been made of the mineral springs in the vicinity of Dawson Springs, and their value.

[6] A. F. Crider, Report on the Geology and Mineral Resourcse of the Dawson Springs Quadrangle, Kentucky Geological Survey, Series IV, Vol. II, Part I, 1914, p. 18.



OUTLINE MAP OF THE
GEOLOGY OF THE DAWSON SPRINGS QUADRANGLE
BY A. H. SUTTON AND A. F. CRIDER
1927
SCALE
LEGEND
PENNSYLVANIAN
MISSISSIPPIAN

CHAPTER III.—STRATIGRAPHY AND PALEONTOLOGY

INTRODUCTION

The hard rock formations which are exposed in the Dawson Springs quadrangle are all Mississippian and Pennsylvanian in age. The oldest strata exposed belong in the Renault limestone, the basal formation of the Chester Series in the Ohio Valley region, and all of the remaining formational units of the Chester that have been recognized and described in the Ohio Valley region are present in the Dawson Springs quadrangle. The older formations are exposed in the southwestern part of the quadrangle, the surface beds becoming younger in passing to the north and northeast.

As much as 800 feet of Pennsylvanian strata are represented in the area, consisting of the basal Pottsville, conglomeratic in places, as well as higher sandstones, shales, and coals, but no attempt has been made to correlate these with the recognized subdivisions of the Pennsylvanian in other parts of the Western Interior Coal Basin.

Although no exposures of formations older than the Chester occur in the Dawson Springs quadrangle, the Spergen, St. Louis, and Ste. Genevieve limestones outcrop in the Princeton quadrangle immediately to the west and in the areas to the south of the Dawson Springs area, and those formations in this general region have been described by Weller in his report on the geology of the Princeton quadrangle. No deep well records are available and nothing has been determined directly concerning the formations not exposed at the surface in the quadrangle. In the Princeton quadrangle, a well 2,017 feet in depth has been drilled near Cedar Hill on the farm of Mrs. W. F. O'Hara, from which a fairly complete series of cuttings has been studied by Weller, who has determined that the strata penetrated consist of 1,630 feet of Mississippian and 387 feet of Devonian formations. His computations, adding 70 feet to the Ste. Genevieve, the amount eroded at the locality of the well, gives a thickness of 1,700 feet for the Mississipian formations

between the base of the Chester and the Devonian.[1] This is considerably greater than has been recorded before for these formations in the Mississippi and Ohio Valley regions. The Devonian strata penetrated by the well consist of 242 feet of Chattanooga shale and 145 feet of limestone apparently Middle Devonian in age.

The Chester Series as it occurs in western Kentucky consists of fifteen distinct formational units, all of which are present in the Dawson Springs quadrangle. The entire series is an alternation of sandstone formations with limestone-shale units. The oldest formation in the Mississippi Valley is the Aux Vases sandstone, but this unit is absent in the Ohio Valley region, its place being taken in part by the unconformity between the Renault limestone and the underlying Ste. Genevieve.

The Chester formations occur in pairs with a sandstone below and a limestone formation above, each set of two formations representing an oscillation of the waters of the sea in which the sediments were deposited. The pairs of formations are separated in some cases by unconformities which are between sandstones above and limestones below, seldom between sandstones and overlying limestones. It has been impossible in some instances to certainly establish the existence of these unconformities in the Dawson Springs quadrangle because of the usual covering of the outcrops by surficial materials, but the general conditions for the various formations as they are known from a wide study would appear to warrant the conclusion that such unconformities exist.

Until 1905 but little attempt to subdivide the Chester Series had been made, the entire series being treated as a single formation, despite the fact that it has a maximum thickness of more than 1,200 feet as compared with a less thickness in most localities of Lower Mississippian formations, which were divided into formational units many years ago.

In 1905 Ulrich[2] made an attempt to break up the Chester by recognizing four formations as follows, beginning with the oldest: (1) Ste. Genevieve limestone, (2) Cypress sandsone, (3) Tribune limestone, and (4) Birdsville formation. Numerous

[1]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, pp. 5-30.
[2]E. O. Ulrich, Prof. Paper No. 36, U. S. Geol. Survey.

modifications of this classification have been suggested and since 1906 Weller[3] has been actively engaged in a study of this important part of the Mississippian System in Illinois and Kentucky, until at present the Chester Series has been split into sixteen distinct and well recognized formations.

In the naming of these formations those which are primarily calcareous are designated as limestones, even though they may contain large amounts of shale or even some arenaceous beds. Likewise those that are dominantly arenaceous are designated as sandstone, despite the fact that in many localities they contain much shale.

Descriptions of the Formations

The columnar section (Plate III) which accompanies this report gives a generalized description of each of the various formations of the quadrangle.

Renault Limestone

Name. The lowest formation of the Chester Series in the Ohio Valley region is the Renault limestone, named by Weller from its occurrence in Renault Township, Monroe County, Illinois. In the Mississippi Valley section the Aux Vases sandstone separates the Renault from the Ste. Genevieve limestone below, but this sandstone is not present in the Ohio Valley section, being represented, in part at least, by the unconformity between the Renault and Ste. Genevieve limestones.

Distribution. The exposures of the Renault in the Dawson Springs quadrangle are only three in number and these are of limited extent. The first of these is in the extreme southwest corner of the quadrangle, in the bed and banks of a small creek; the second is in the bed and along the banks of another small creek about one and three-quarters miles east of the first one mentioned, in Trigg County; the third is in the northwestern part of the southwest rectangle in the fault block bounded by faults 14, 15, and 19. The Areal Geology Map (Plate I) shows the distribution in detail.

Lithologic Characters. Only the uppermost beds of the Renault outcrop in the Dawson Springs quadrangle, so that from

[3]Stuart Weller, The Chester Series of Illinois, The Journal of Geology, Vol. XXVIII, 1920, p. 285.

PLATE III

COLUMNAR SECTION

SYSTEM	SERIES	GROUP	FORMATION	SYMBOL	SECTION	THICKNESS (in feet)	CHARACTER OF ROCK
			Alluvium	Qal		10-20	
PENNSYLVANIAN			Undifferentiated Pennsylvanian	P		800±	Conglomerate bed at the base followed by interstratified sandstones and shales, with some thin limestone and coal layers
MISSISSIPPIAN	CHESTER	UPPER	Kinkaid	Mk		0-160	Alternating limestone and shale beds of variable thickness
			Degonia	Md		10-20	Fine grained, yellow to brown sandstone
			Clore	Mcl		40±	Lower portion, interbedded shale and ls.-midde, shale-upper, ls. and shale
			Palestine	Mp		60-120	Massive brown sandstone in lower portion becoming more shaly in upper part Bluff forming
			Menard	Mm		65±	Lower portion, interbedded grey limestone and shale with more shale in upper portion
			Waltersburg	Mwb		½-6	Chiefly shale with some redish brown ss.
			Vienna	Mv		15-50	Chiefly shale with cherty limestone layers in lower part in places
			Tar Springs	Mts		160-200	More or less massive, cross-bedded sandstone in lower portion - shaley in middle portion - massive towards top Fine grained-yellow to brown in color Bluff forming
		MIDDLE	Glen Dean	Mgd		40-50	Alternating limestone and shale beds. Locally a thin cong't at base
			Hardinsburg	Mh		40-60	Massive sandstone below changing to thin sandstone layers and shale in upper part.
			Golconda	Mg		30-50	Chiefly shale and thin limestone layers
			Cypress	Mc		40	Thinly bedded, fine textured, brown to yellowish sandstone.
		LOWER	Paint Creek	Mpc		100±	Grey limestone with interbedded shale layers of varying thickness-chiefly crystalline, but in part hard and dense.
			Bethel	Mb		40	Light brown, moderately coarse grained sandstone.
			Renault	Mr		60-80	Dense, compact to more or less crystalline limestone layers separated by a shaley parting-usually grey-some yellow or buff.

these exposures alone not much can be determined concerning the character of the formation as a whole. These upper beds are gray in color, rather dense and compact in texture and weather to smooth rounded surfaces. They vary from a few inches in thickness to as much as a foot or fifteen inches and are separated by thin shaly partings.

The examination of the Renault was carried somewhat beyond the limits of the quadrangle in order to obtain a better idea of the character of the rock, as well as make suitable fossil collections. These studies show that the formation is dominantly limestone, rather persistently gray in color, although some nearly white beds are present locally, as well as some yellow and buff colored strata. Most of the layers are dense and compact, but some more or less crystalline members do occur. Almost all of them are hard and break with a splintery fracture. Although it has not been observed by the writer in this quadrangle, a more or less persistent limestone conglomerate or breccia layer is reported at the base of the formation in this general region. This layer is commonly about one foot in thickness and no doubt is associated with the unconformity between the Renault and the underlying Ste. Genevieve limestone.

Thickness. Only about 30 feet of the upper part of the Renault is exposed in the Dawson Springs quadrangle. In his description of the Renault in the Princeton quadrangle, just west of this area, Weller reports an average thickness of about 80 feet, with a minimum of 60 feet and a maximum of nearly 100 feet. The same general thickness no doubt exists in this area.

Stratigraphic Relations. While the base of the Renault is not exposed in the Dawson Springs quadrangle, some remarks concerning the character of its contact with the underlying Ste. Genevieve will not be out of place here. The unconformity at the top of the Ste. Genevieve limestone is the most important break in the stratigraphy of the Mississippian System in the Ohio and Mississippi Valleys, and marks the division between the Iowa and Chester Series. The withdrawal of the waters from the interior of the continent seems to have been more complete at this time than at any other during the Mississippian Period. None of the succeeding invasions of the sea during Mississippian times covered as much of the land as did the Ste.

Genevieve waters, and with the reinvasion of the waters in Chester times a fauna characterized by many different forms was introduced into this region. Further evidence of unconformity between the two formations is the general presence of the conglomerate or breccia bed at the base of the Renault.

The contact between the Renault and the overlying Bethel marks an abrupt change in sedimentation from limestone to sandstone. This relation has been observed not only in the three areas of Renault outcrop in the Dawson Springs quadrangle but also in the area immediately to the south. Where the contact between the Renault and Bethel has been observed in Hardin County, Illonois,[4] there is no doubt of an unconformity, and the same condition doubtless is true in this area.

Paleontology. The most characteristic fossil of the Renault is the crinoid genus, *Talarocrinus.* A number of species of this genus have been described from the faunas of the formation in Kentucky and Illinois. The genus is entirely unknown in any fauna of the Ste. Genevieve limestone, and although occurring in the Paint Creek, the next higher limestone of the Chester, it is far more rare than in the Renault and it is unknown from any higher formation of the Chester Series. It is thus a good horizon marker for the Renault. The bryozoan, *Cystodictya labiosa* is another form, rarely met with in the Renault, which is limited in its occurrence to the Renault and Paint Creek, being unknown from any higher formations. In contrast with *Talarocrinus, Cystodictya* is relatively rare in the Renault, becoming abundant in the Paint Creek. Another characteristic element of the Renault faunas is the presence for the first time of the pyriform types of the blastoid, *Pentremites.*

The Chester faunas are strikingly different, when considered as an assemblage of forms, from any known from the lower Mississippian formations. Some forms present in the Renault are survivors from earlier times, but even the presence of these cannot take from the Chester faunas their appearance of a new and different assemblage of forms.

The best horizons from which to collect fossils in the Renault are the shaly partings between the limestone layers. The limestones themselves are not of a character that has permitted the preservation of fossils in good condition for collecting. Only one small Renault collection was made in the Dawson Springs quadrangle, from the exposure in the extreme southwest corner of the area, and in this collection there are none of the species entirely characteristic of the formation, although the collection as a whole is typically Chester in its characters.

[4]Geology of Hardin County, Ill. State Geol. Survey Bulletin No. 41, 1920, pp. 146-147.

Renault Fossils from Southwest Corner of Quadrangle

Triplophyllum spinulosum (M.-E. & H.)
Crinoid stems and plates.
Fenestella cestriensis Ulrich
Fenestella elevatipora Ulrich
Productus ovatus Hall
Productus inflatus McChesney
Diaphragmus elegans (N. & P.)
Spirifer increbescens var. transversa Hall
Spirifer sp.
Cleiothyridina sublamellosa (Hall)
Composita trinuclea (Hall)

A more complete collection, containing characteristic Renault species, was made just south of the Dawson Springs quadrangle in the vicinity of Cerulean Springs. This collection contains a number of species characteristic of the Renault elsewhere and leaves no doubt of the identity of the formation in this locality. The list of fossils collected follows.

Renault Fossils From Near Cerulean Springs

Triplophyllum spinulosum (M.-E. & H.)
Dichocrinus girtyi Weller
Talarocrinus buttsi Ulrich
Talarocrinus trijugis M. & G.
Talarocrinum dewolfi Ulrich
Crinoid stems and plates
Pentremites princetonensis Ulrich
Pentremites buttsi Ulrich
Fistulipora excelens Ulrich
Eridopora punctifera Ulrich
Batostomella sp.
Meekopora sp.
Anisotrypa solida Ulrich
Fenestella cestriensis Ulrich
Fenestella tenax Ulrich

Septopora cestriensis Prout
Polypora spinulifera Ulrich
Polypora approximata Ulrich
Lyropora quincuncialis Hall
Orthotetes kaskaskiensis (McChesney)
Productus ovatus Hall
Productus sp.
Diaphragmus elegans (N. & P.)
Girtyella indianensis (Girty)
Girtyella brevilobita (Swallow)
Spiriferina transversa (McChesney)
Spirifer breckenridgensis Weller
Spirifer increbescens var. transversalis Hall
Spirifer sp.
Eumetria vera (Hall)
Cliothyridina sublamellosa (Hall)
Composita trinuclea (Hall)
Allorisma clavata (McChesney)
Leda sp.
Orthonychia chesterensis M. & W.
Orthonychia sp.
Bellerophon sp.
Platyceras sp.
Phillipsia sp.

Correlation. A complete discussion of the correlation of the Renault may be found in the report on Hardin County, Illinois.[5] Ulrich originally included the formation in his Ohara member of the Ste. Genevieve limestone and on the basis of the Chester type of fauna present, included all of the Ste. Genevieve in the Chester Series. Later detailed studies have shown the identity of the "Upper Ohara" with the typical Renault of the Mississippi Valley section, and the formation has been traced and mapped in detail from Caldwell County, Kentucky, to and across Union County, Illinois, into Perry and Ste. Genevieve Counties, Missouri, and from there back into Randolph and Monroe Counties, Illinois, where the type locally occurs.

In the Dawson Springs quadrangle the Renault is correlated on the basis of the characteristic Renault forms of *Talarocrinus*, the typical Chester aspect of the fauna in general, and

[5]Stuart Weller, Geology of Hardin County, Illinois State Geol. Survey, Bulletin 41, 1920, pp. 150-159.

the stratigraphic position of the formation beneath the lowest Chester sandstone formation.

Bethel Sandstone

Name. The Bethel sandstone was named by Butts from exposures near Bethel School in Crittenden County, Kentucky. Ulrich[6] originally identified this sandstone in his description of the Mississippian section of western Kentucky, with the Cypress sandstone of Engelmann, which in turn was described from southern Illinois, but Weller has established the fact that the Cypress of Ulrich is not the same as the Cypress of Engelmann, but a lower member of the Chester. To obviate this difficulty in nomenclature, Butts[7] proposed the name Bethel for this formation, a name which has been adopted and used by all later workers.

Distribution. The Bethel sandstone is exposed at only three localities in the Dawson Springs quadrangle. In the southwestern part of the quadrangle a considerable region is underlain by the Bethel, which occupies a relatively flat area below the Paint Creek limestone in the steeper slopes above, and with the Renault outcropping still lower down in the two stream courses mentioned in connection with the discussion of that formation.

The other outcrops are in the northwest part of the southwest rectangle, one in the same fault block in which the Renault occurs, the other just south of fault No. 19. This southern outcrop is limited on the east by fault 18 and forms a small triangular area having the Bethel as the surface formation.

Lithologic Characters. The Bethel is a moderately fine grained quartz sandstone, more or less friable, and as coarse or coarser than most of the other Chester sandstones of this region. It is brown in color when fresh, but upon weathering the surface becomes dark brown to almost black. Much of the formation, especially the upper part, is rather massive, in layers of considerable thickness separated by relatively inconspicuous partings. Locally it forms low bluffs along the streams. The

[6]E. O. Ulrich, Professional Paper U. S. Geological Survey, No. 36, 1905, p. 53.
[7]Charles Butts, Mississippian Series in Western Kentucky. Kentucky Geol. Survey, 1918, p. 63.

thicker beds are often cross bedded and ripple marked. The lower portion is more thinly bedded in layers of three or four inches in thickness, which break up on exposure into slabs that commonly form "shingle" along the stream beds.

Thickness. As no suitable exposures for exact measurement are available, the thickness of the Bethel in this quadrangle has been determined by estimation. Judging from the interval between the Renault and the Paint Creek in the southwestern corner of the quadrangle, the thickness can not be far from 40 feet. In the more northern localities the thickness, estimated in the same way, appears to be somewhat less, perhaps more nearly 30 feet.

Stratigraphic Relations. Presumably the contact between the Bethel and the underlying Renault is one of unconformit, as has been pointed out in the discussion of the Renault limestone. The actual contact with the overlying Paint Creek limestone has not been observed anywhere within the quadrangle, but in the few Bethel outcrops there seems to be a shale member of the Paint Creek just above the Bethel and it is possible that the change from one formation to the other is a gradual transition from coarser to finer sediment. Weller states that in places in the Princeton quadrangle there seems to be an abrupt change from sandstone to limestone above, and that an unconformity between the Bethel and Paint Creek is suggested in Hardin County, Illinois, but no such abrupt change has been observed in the Dawson Springs quadrangle.

Paleontology. No fossils of any diagnostic value have been collected in the Bethel sandstone anywhere in the quadrangle. Some casts of stems of *Lepidodendron* were found, but not of such a character as to serve as a means of identification of the formation. This same situation is true of almost all of the Chester sandstones, few of them displaying either lithologic or paleontologic features whereby they may be surely identified. The problem of identification resolves itself into the determination of the limestones and letting the stratigraphic position, thickness and physical characteristics of the sandstones determine their identity.

Correlation. The correlation of the Bethel sandstone of this area rests entirely upon its position between the Renault

and Paint Creek limestones. The Bethel has been traced from the Princeton, Kentucky, quadrangle to near Anna, Union County, Illinois. It thins toward the western limit of this exposure and also toward the east. According to Butts, it thins out near Fairview close to the county line between Christian and Todd Counties, Kentucky, and J. Marvin Weller[8] reports a complete absence of the formation in Edmonson County, Kentucky.

In Breckenridge County, Kentucky, a formation has been described by Butts as the Sample[9] sandstone which, at the time of its description, was considered as being higher in the Chester Series than the Bethel. It seems evident, however, that the Sample sandstone is the time equivalent of the Bethel sandstone farther south and west in Kentucky. The writer, in company with Stuart Weller and J. Marvin Weller, visited this area in 1925 and was able to find characteristic Renault fossils in the limestone formation underlying the so-called Sample sandstone, and Paint Creek fossils above it.

The Bethel of this area is also considered as the equivalent of the Yankeetown chert of the Mississippi River Chester section in Monroe and Randolph Counties, Illinois.[10]

Paint Creek Limestone

Name. The Paint Creek formation was originally named by Weller from exposures in Monroe and Randolph Counties, Illinois, the type section being along a stream in southern Monroe County, where the formation contains a characteristic red shale member which is the source of the red color of the water of the stream. The formation has been traced and mapped across these counties, southward across the Mississippi river into Perry County, Missouri, eastward across southern Illinois, and in Livingston, Crittenden, and Caldwell Counties, Kentucky. In 1924 the Paint Creek was mapped in detail in Edmonson County, Kentucky, thus giving a good conception of the charac-

[8]J. Marvin Weller, Geology of Edmonson County, Kentucky Gelogical Survey, Series VI, Vol. 28, 1927. Pp. 109-110.

[9]Charles Butts, Mississippian Series in Western Kentucky, Kentucky Geological Survey, 1918, pp. 70-73.

[10]Stuart Weller, The Chester Series in Illinois, Journal of Geology, Vol XXVIII, 1920, pp. 292-294.

ter of the formation throughout a considerable section of the Mississippi and Ohio Valleys.

In his original description of the Chester Series in western Kentucky, Ulrich defined the Tribune limestone as an oolitic formation overlying the Bethel sandstone, which he then considered as Cypress. The formation was named from exposures at Tribune, Kentucky, beds which have since been shown by Weller to be Menard. Ulrich[11] has since stated that the formation which he intended to designate as Tribune, is a limestone which outcrops in western Christian County, Kentucky, near the Christian-Caldwell County line, an area included in the Dawson Springs quadrangle.

Butts[12] has attempted to eliminate this confusion, caused by the naming of a formation overlying the Bethel (Cypress of Ulrich) sandstone, from exposures at Tribune which are much higher in the section, by the introduction of the name Gasper Oolite as a substitute for Tribune. However, the name Gasper, as used, includes not only the typical Paint Creek, but in the type locality, also the Renault, since the Bethel or Sample sandstone is not present in that section. The two or three feet of clay beds present in the Paint Creek section (Ulrich's type locality for the "Tribune Limestone") along the Princeton Pike in western Christian County, cannot be the equivalent of the Sample sandstone, as stated by Butts, but is a local shale member in the midst of the Paint Creek, consequently the limestone formation in western Kentucky to which Ulrich applied the name Tribune is the exact equivalent of the Paint Creek of southern Illinois, and even if the Gasper as defined were equivalent to the so-called Tribune, the name would be ruled out on the basis of priority, in favor of Paint Creek.

Distribution. In the Dawson Springs quadrangle the exposures of the Paint Creek are chiefly in the southwestern portion of the area, in an almost continuous belt along the Princeton-Hopkinsville pike from the point where it first enters the southern border of the quadrangle to the place where it passes into the Princeton quadrangle to the west. The beds are offset

[11] E. O. Ulrich, Mississippi Series in Western Kentucky, Kentucky Geological Survey, 1918, pp. 91-92.

[12] Charles Butts, Mississippian Series in Western Kentucky, Kentucky Geological Survey, p. 64.

slightly—about 20 feet—by one east-west fault, No. 32, which crosses this part of the quadrangle, and the hills are capped in two places by the Cypress sandstone. This constitutes the greatest single exposure of the Paint Creek and includes the type locality for the original Tribune limestone.

Fig. 8.—View of the thick oolitic layer in the lower part of the Paint Creek along roadside near Caldwell-Christian County line.

There are other smaller, discontinuous outcrops in the fault blocks to the north and east of this larger exposure, the details of which are shown on Plate I.

Lithologic Characters. The Paint Creek is largely a limestone formation with varying amounts of shale interbedded with the limestone layers. In general the lower portion of the formation is more largely limestone layers with shale partings, than shale, although in some localities the lower part of the formation is dominantly shale. The middle portion of the section consists of beds which are more shaly, while the upper part is again chiefly limestone with shale partings. In places the top member is a shale bed 10 to 15 feet in thickness, dark gray in color, underlying the Cypress, while in other places the top of the formation is limestone. The calcareous sandstone layer which has been reported as occurring locally in the lower part of the Paint Creek in the Princeton quadrangle[13] has not been observed in the Dawson Springs. Some of the limestone ledges in the lower portion of the formation are oolitic in texture, white

[13] Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, p. 46.

in color, and contain a fauna of diminutive species, including many molluscs, a feature more or less characteristic of most oolitic beds of the Chester. Some of these beds attain considerable thickness, one in particular in the exposure along the Princeton Pike near the Christian-Caldwell county line having a maximum thickness of seven feet four inches. Locally some of the higher layers are oolitic, but the formation as a whole is apparently not as oolitic as one would infer from the earlier descriptions of the "Tribune" of western Kentucky.

As a whole the limestone members are more crystalline than the Renault. They are generally gray in color and weather with rough surfaces which are covered with mosses and lichens in many places. Other beds are hard, rather dense or finely crystalline, dark gray to blue in color, and weather smooth. Locally the upper layers are yellowish or buff and upon exposure weather rather rapidly.

The shales are for the most part non-fissile and gray, some darker than others, becoming almost blue when wet. They are as variable as the limestones in their characters.

In most localities the outcrops are more or less covered with talus or weathered material, making it difficult or almost impossible to measure detailed sections. However, two fairly complete sections have been studied, one in the hillside along the Princeton-Hopkinsville pike in Christian County near the boundary line between Caldwell and Christian counties, and the other along the road leading southwest from the Princeton road about two miles northwest of Bainbridge Church. These two sections, about a mile apart, give some idea of the variations of the beds within the formation.

Paint Creek Section Along Princeton Pike Near Caldwell-Christian County Line

	Feet	Inches
Cypress sandstone		
Limestone layers with shale partings, limestone beds with maximum thickness of about 3 feet 6 inches—some beds oolitic	20	
Chiefly shale with thin interbedded limestone layers	30	
Gray limestone	1	6
Shale		2
Light gray limestone	1	4

Shale	1	6
Yellowish, crystalline, fossiliferous, rapidly weathering limestone	1	10
Gray shale		8
White oolitic limestone	7	4
Gray, hard, finely crystalline limestone layers with shale partings	35	
Base formation concealed		
	99	4

Paint Creek Section Along Road Southwest From Princeton Pike, Two Miles Northwest of Bainbridge Church

	Feet
Cypress sandstone	
Limestone layers separated by shale beds. Some limestone beds, gray, hard and dense, some crystalline, and crumbling upon weathering, others white and oolitic	50
Gray shale	15
Two limestone ledges separated by 1 foot 6 inches of shale	5
Shale with interbedded limestone	40
Bethel sandstone	
	110

Thickness. The average thickness of the Paint Creek in the Dawson Springs quadrangle seems to be slightly more than 100 feet, the two measured sections being 99 feet 4 inches and 110 feet respectively. In the case of the thinner section the lower part of the formation is not exposed. There is probably little variation from this thickness anywhere in the quadrangle.

Stratigraphic Relations. In the discussion of the Bethel sandstone it was brought out that the presence or absence of an unconformity below the Paint Creek can not be surely established for this area. In most places where there is a fairly good opportunity to view the contact, the sandstone appears to be directly overlain by the shale beds of the lower Paint Creek, suggesting little if any break in the continuity of sedimentation in the passage from one formation to the other.

The contact of the overlying Cypress sandstone in places with shale members of the Paint Creek and in other localities with limestone beds in an area no larger than that occupied by

the two formations would appear to indicate a slightly eroded surface on which the Cypress was deposited, and consequently suggests the existence of unconformable relations between the two. However, it is difficult or almost impossible to obtain a definite contact between the two formations because of the disintegration of the shale and the slumping of the weathered material.

Paleontology. The Paint Creek is one of the most abundantly fossiliferous formations of the Chester in the Dawson Springs quadrangle. As a rule the limestone layers are only sparingly fossiliferous and the fossils present are poorly preserved and difficult to obtain. The best parts of the formation for fossil collecting are the calcareous shale members in the middle and upper portions. In areas of favorable exposure the fossils are weathered out and remain on the surface where they may be readily picked up.

In contrast with most of the limestone layers, some of the oolitic beds are abundantly fossiliferous, the fossils being unique in that they are all of diminutive species. Some of the species present are the same as occur in other parts of the Paint Creek, but are for the most part smaller forms. In addition to the usual types of brachiopods, blastoids, bryozoa, etc., these oolitic layers contain a strikingly different fauna composed of many small species of pelecypods and gastropods, many of which are undescribed species.

Without doubt the conditions favorable for the deposition of oolitic limestones were conditions unfavorable for the growth of robust forms of life. Perhaps this was due to the scarcity of food material in water so saturated with calcium carbonate. At any rate the situation suggests an interesting problem worthy of study. On the other hand the presence of so many species of pelecypods and gastropods, forms relatively rare in other horizons of the Paint Creek, indicates the existence of favorable conditions for the development of this particular type of life. The same types of faunas are to be found in other oolitic limestones of the Chester Series and also calcareous oolites other than those of the Chester formations. They have been reported

especially from the Spergen limestone from Spergen Hill, Indiana, and from oolitic limestones of the Pennsylvanian.[14]

In 1915 Weller made an excellent collection from the higher oolitic beds (Ulrich's type Tribune) of the Paint Creek along the Princeton road near the boundary line between Caldwell and Christian Counties. A list of the fossils collected by him and partly identified by the writer is given below.

Paint Creek Fauna From Oolitic Beds in Christian County Near Caldwell-Christian County Boundary Line.

Pentremites sp.
Fistulipora sp.
Anisotrypa macropora McFarlan (Mss)
Anisotrypa sp.
Rhombopora sp.
Fenestella several species
Archimedes several species
Polypora cestriensis Ulrich
Polypora sp.
Glyptopora pustulifera, McFarlan (Mss)
Glyptopora punctipora Ulrich
Crania chesterensis Miller & Gurley
Schuchertella costatula (Hall & Clarke)
Productus ovatus Hall
Productus parvus Meek & Worthen
Spirifer increbescens var. transversalis, Hall
Girtyella indianensis (Girty)
Recticularia setigera (Hall)
Eumetria vera (Hall)
Cliothyridinia sublamellosa (Hall)
Composita trinuclea (Hall)
Sphenotus sp.
Nucula sp.
Leda sp.
Myalina two species
Schizodus sp.
Aviculopecten sp.
Cypricardinia sp.
Parallelodon micronema (Miller & Gurley)
Parallelodon sp.
Leiopteria sp.
Edmondia sp.
Bellerophon sp.

[14]Sayre, A. Nelson, Fauna of the Drum Limestone, Unpublished Manuscript.

Mourlonia sp.
Naticopsis sp.
Orthonychia sp.
Zygopleura sp.
Aclisina sp.
Orthoceras sp.
Phillipsia sp.

A highly diagnostic Paint Creek fossil which can be used in recognition of the formation, is the bryozoan *Cystodictya labiosa*. This species, although present in the Renault, is far more abundant in the Paint Creek, and by careful search it may be found in practically every Paint Creek exposure which is at all fossiliferous. It is not known except in these two formations. Several good collections were secured from the more shaly horizons of the Paint Creek, but as they duplicate each other to a large extent only two of them are recorded here. The most complete collection was made about three-quarters of a mile south of Pleasant Grove Church along the road to Sizemore School from the Princeton-Hopkinsville road.

Paint Creek Fauna From South of Pleasant Grove Church

Triplophyllum spinulosum (M.-E. & H.)
Agassizocrinus sp.
Pterotocrinus serratus Weller
Crinoid stems and plates
Pentremites godoni DeFrance
Pentremites pyramidatus Ulrich
Tabulipora tuberculata McFarlan (Mss)
Tabulipora sp.
Fistulipora excelens Ulrich
Meekopora eximia Ulrich
Cystodictya labiosa Weller
Rhombopora tabulata Ulrich
Lyropora sp.
Fenestella exigua Ulrich
Fenestella several species
Archimedes terebriformis Ulrich
Archimedes swallovanus (Hall)
Archimedes invaginatus Ulrich
Polypora cestriensis Ulrich
Streblotrypa nickelsi Ulrich
Schuchertella costatula (Hall & Clarke)
Pustula genevieviensis Weller

Productus sp.
Diaphragmus elegans (Norwood & Pratten)
Girtyella indianensis (Girty)
Girtyella brevilobata (Swallow)
Spirifer increbescens var. transversalis Hall
Spirifer leidy (Norwood & Pratten)
Spirifer sp.
Cliothyridina sublamellosa (Hall)
Conocardium sp.
Cypricardina cf. indianensis (Hall)
Parallelodon sp.
Aviculopectin baldwinensis Weller (Mss.)
Porcellia sp.
Bellerophon sp.
Orthocertite genus and species undescribed
Phillipsia sp.

In addition to the forms here recorded, the washing and screening of a limited amount of fine material yielded several species of minute undescribed gastropods and also several species of ostracods, which likewise seem to be undescribed forms.

Another good collection was made from almost the highest shale beds of the formation along the Princeton-Hopkinsville road about two miles northwest of Bainbridge Church.

Paint Creek Fauna From Northwest of Bainbridge Church

Triplophyllum spinulosum (M.-E. & H.)
Agassizocrinus two species
Pterotocrinus serratus Weller
Crinoid plates and stems
Pentremites gemmiformis Hambach
Fistulipora excelens Ulrich
Meekopora eximia Ulrich
Anisotrypa macropora McFarlan (Mss.)
Tabulipora terberculata (Prout)
Tabulipora texta McFarlan (Mss.)
Glyptopora punctipora Ulrich
Cystodictya labiosa Weller
Fenestella cestriensis Ulrich
Fenestella exigua Ulrich
Polypora multispinosa McFarlan (Mss.)
Polypora nodolinearis McFarlan (Mss.)
Archimedes swallovanus (Hall)
Archimedes invaginatus Ulrich
Archimedes terebriformis Ulrich

Septopora subquadrans Ulrich
Streblotrypa nicklesi Ulrich
Rhombopora sp.
Orthotetes kaskaskiensis (McChesney)
Productus cf. inflatus McChesney
Productus sp.
Diaphragmus elegans (N. & P.)
Spiriferina spinosa (N. & P.
Spirifer increbescens var. transversalis Hall
Spirifer sp.
Girtyella brevilobita (Swallow)
Dielasma illinoisensis Weller
Recticularia setigera (Hall)
Cliothyridina sublamellosa (Hall)
Composita trinuclea (Hall)
Euomphalus sp.
Orthoceras sp.
Phillipsia sp.

Correlation. Correlation of the Paint Creek formation in the Dawson Springs quadrangle has been based on both paleontology and stratigraphy. The fauna of the formation possesses many features in common with those which have been described from other Paint Creek areas of western Kentucky and southern Illinois. Aside from the abundance of the bryozoan, *Cystodictya labiosa,* the formation is rich in Pentremites, some species of which are highly characteristic.

In recent publications both Butts[15] and Ulrich[16] have substituted the name Gasper for Tribune because of the unfortunate choice of the latter name. The typical Tribune of Ulrich is the Paint Creek of the Dawson Springs quadrangle, which has been shown to be the equivalent of the typical Paint Creek of southern Illinois. The typical Gasper was named from exposures farther east in Kentucky and in Breckinridge County it has been described as consisting of two limestone members separated by the Sample sandstone, but, as has been brought out in the discussion of the Bethel sandstone, the Sample and Bethel sandstones are exact equivalents. Butts and Ulrich also have corelated the Gasper, at which type locality no Bethel sandstone

[15]Butts, Stephenson, Cooke and Adams, Geology of Alabama, Geological Survey of Alabama, Special Report No. 14, 1926, pp. 185-189.

[16]E. O. Ulrich, Mississippian Series in Western Kentucky, Kentucky Geological Survey, 1918, p. 92.

exists, with the combined Renault and Paint Creek formations of western Illinois, a perfectly justifiable correlation, but in the Dawson Springs quadrangle, with the Bethel sandstone present, they consider the Paint Creek alone, as equivalent to the whole of the Gasper farther northeast in Kentucky. In order to establish such a correlation Butts[17] has considered a clay bed two or three feet thick in the midst of the Paint Creek as the equivalent of the Sample sandstone in Breckinridge County. With such an interpretation the Paint Creek of the Dawson Springs quadrangle was divided into an upper and a lower division supposed to be the equivalents of the so-called upper and lower Gasper of Breckinridge County where the "Sample" sandstone was recognized. There is neither paleontological nor stratigraphic basis for such a division of the Paint Creek, since the fossils both above and below the clay bed are typically Paint Creek in character, and good exposures of Bethel sandstone with the underlying limestone containing typical Renault faunas occur less than two miles southwest of this area, with no faults intervening to break the continuity of the beds.

The correlation of the Paint Creek formation (Ulrich's typical "Tribune Limestone") of the Dawson Springs quadrangle with the Paint Creek in southern Illinois and with that portion of the Gasper lying above the "Sample" sandstone in Breckinridge County is confirmed on both paleontological and stratigraphic grounds. The same evidence establishes the equivalency of the Sample sandstone of Breckinridge County with the Bethel of this area and the lower part of the Gasper of the eastern areas as the equivalent of the Renault limestone of the Dawson Springs quadrangle.

Cypress Sandstone

Name. The Cypress sandstone was originally named by Englemann from exposures along Cypress Creek in Union County, Illinois. In his original report on western Kentucky, Ulrich described a sandstone formation as Cypress which is now known to be the Bethel. In some parts of western Kentucky

[17]Charles Butts, Mississippian Series in Western Kentucky, Kentucky Geological Survey, 1918, pp. 72-73.

the Cypress was originally described as bed No. 1 of the Birdsville formation by Ulrich,[18] but much of the supposed bed No. 1 of the original Birdsville formation is really the Tar Springs sandstone, which is considerably higher in the Chester section. The true Cypress has been traced and mapped in detail across southern Illinois and into western Kentucky.

Distribution. The most extensive outcrops of the Cypress in the Dawson Springs quadrangle exist in the southwestern portion of the mapped area on both sides of the Princeton-Hopkinsville road, in the same fault blocks that contain the outcrops of the Paint Creek limestone. In addition to the larger exposures, the Cypress also caps several small hills and forms the valleys of some of the streams in the southwestern part of the quadrangle. Other areas of outcrops of considerable extent are in the fault block bounded by faults 8, 9, 12, and 14, where it is the surface formation in three localities, forming a long, narrow belt along the base of the hill north of Hart School, capping the hill in the southern part of the fault block from Crossroads Church to the northeastern part of the block, and appearing in the hillside in the southeastern corner of the block in fault contact with higher Chester beds to the east.

The Cypress is a relatively thin formation and because of its limited thickness is a much less important sandstone formation than some of the higher Chester sandstones of the quadrangle. It occurs for the most part as a thin capping formation giving rise to considerable areas of level upland above the relatively gentle slopes underlain by the Paint Creek limestone.

Lithologic Characters. The Cypress is a thinly bedded quartz sandstone commonly with minor amounts of shale in partings between the sand layers, but in some localities it exhibits a much more shaly facies. At one locality a thin impure limestone layer, three inches in thickness has been intercalated in the midst of the sandstones, and from this the only fossil collection from the Cypress was obtained. In places some of the sand layers are thicker, reaching a maximum of three feet. These thicker beds are present near both the top and the base of the formation but do not occur in the middle portion.

[18] Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, pp. 31-32.

The sand composing the rock is of a finer texture than that of the Bethel. In color, it is usually brown, becoming yellowish in places, with the surface of the beds often ripple marked and the layers occasionally cross bedded. These features suggest deposition in rather shallow water and the fine texture of the sand may be an indication of its transportation for a considerable distance, or else the result of wear, more or less in situ by the waves and currents of the shallow water in which the sand was deposited.

Nowhere within the limits of the Dawson Springs quadrangle has it been possible to obtain an accurate and complete section, in detail, of the entire formation because of the prevalence of detrital material which has slumped down from the shaly beds above. One partially complete section was measured along the Princeton-Hopkinsville road in western Christian County. The lower portion of the formation is present but, unfortunately, the upper beds have been removed by erosion, so that it is impossible to get the total thickness and consequently the section as given below does not include the entire formation.

Cypress Section Along Roadside in Western Christian County

	Feet	Inches
Thin bedded yellowish sandstone with layers averaging about 3 inches in thickness	23	
Massive, yellowish brown sandstone layer	3	3
Thin bedded brown sandstone, layers 3 to 4 inches thick	2	
	28	3

Thickness. The total thickness of the Cypress has nowhere been observed within the quadrangle. In the northern exposure in the vicinity of Crossroads Church the thickness is variable. North of the church the maximum thickness which can be assigned to the formation on the basis of the interval between the Paint Creek and Golconda, is approximately 25 feet. In the eastern part of the same fault block the thickness is somewhat greater, and may be as much as 35 or 40 feet.

Judged by these data the thickness of the Cypress in the Dawson Springs quadrangle seems to be not much over 33 or 35 feet and certainly not more than 40 feet.

Stratigraphic Relations. Inasmuch as the actual contacts with the overlying Golconda and underlying Paint Creek formations have not been observed in the quadrangle, the stratigraphic relations of the Cypress with these two formations have not been

Fig. 9.—Thin beds of the upper Cypress, near Caldwell-Christian County line in Christian County.

definitely established. However, as has been indicated before, the lower beds of the Cypress seem to be in contact with shale members of the Paint Creek in places, while elsewhere they rest upon more calcareous beds, suggesting the existence of a more or less uneven surface upon which the Cypress was deposited. This fact together with the irregular variations in thickness of the Cypress lends some support to the existence of an unconformity between the two formations. However, it must be kept in mind that the Paint Creek itself is variable in character and the presence of different kinds of sediment at the top of the formation may be due to local variations in character of sediment at the same stratigraphic horizon.

No evidence of an unconformity between the Cypress and the overlying Golconda has been observed within the area, the two formations appearing rather to represent a gradual transitional change from sandstone to shale deposition.

Paleontology. As a rule the Cypress is unfossiliferous except for fragmental remains of Lepidodendrons and perhaps some other plants. In one exposure, about one and a quarter

miles southeast of Crossroads Church along the new Sandlick road, near the lower part of the formation a thin, impure, limestone layer is present, which is fossiliferous. The species present are the usual Chester types of gastropods, pelecypods, and brachiopods. One brachiopod, *Rhynchopora perryensis*, known elsewhere only from the Golconda, exists in considerable numbers in this fauna.

Cypress Fossils From Southeast of Crossroads Church

Triplophyllum spinulosum (M.-E. & H.)
Orthotetes kaskaskiensis (McChesney)
Diaphragmus elegans (N. & P.)
Rhynchopora perryensis Weller
Spirifer sp.
Composita trinuclea (Hall)
Nucula sp.
Leda sp.
Aclisina sp.
Hormotoma sp.
Bellerophon sp.
Phillipsia sp.
Orodus sp.

Correlation. The correlation of the Cypress sandstone is based upon its stratigraphic position between the underlying and overlying limestone formations. These formations have been definitely determined as Paint Creek and Golconda on the basis of the contained fossils, which establishes the position of the intervening sandstone as being the same as that of the typical Cypress sandstone in southern Illinois.

Golconda Limestone

Name. The Golconda limestone was first named by Butts from exposures just north of Golconda in Pope County, Illinois, in the bluffs of Lusk Creek and Ohio River.[19] The formation has been recognized and mapped in Hardin, Pope, and Jackson counties, Illinois, and Livingston, Crittenden, and Caldwell Counties, Kentucky. The presence of the formation in the Dawson Springs quadrangle has been fully established by the fossil collections that have been made from it here.

[19]Charles Butts, Mississippian Series in Western Kentucky. Kentucky Geological Survey, 1918, p. 91.

Distribution. Outcrops of the Golconda in the Dawson Springs quadrangle are relatively few and are confined to a narrow, faulted belt extending in a northwest-southeast direction between the vicinity of Crossroads Church at the northwest end and Bainbridge Church at the south. Within the area limiting the outcrops, the actual exposures are few because of the shaly character of the beds which permits rapid weathering and the accumulation of much residuum which masks the outcrops.

One isolated occurrence of the lower portion of the Golconda is in the fault block bounded by faults 19, 32, and 33, about a half mile northeast of Pleasant Grove Church where the formation lies as a thin cap on a small hill. The area of outcrop is small in extent and unusual, in that essentially all other hills of the area are capped by sandstone which is much more resistant to erosion.

Within the faulted area of the quadrangle the Golconda underlies the surface in parts of four fault blocks. In the block bounded by faults 37, 38, 39, and 40 it occurs as a sinuous belt around the base of the steep slope of the upland to the north. In the block surrounded by faults 32, 37, and 38, adjacent to the last one, the Golconda also occurs under similar conditions. In the next fault block to the northwest, bounded by faults 19, 32, 33, and 34 it is present on all sides along the streams, the uplands being surfaced by the Hardinsburg sandstone. The fifth occurrence in the western part of the quadrangle is in fault block bounded by faults 8, 9, 12, and 14 Here the formation outcrops in the side of the hill north of Crossroads Church in a narrow belt completely around the south side of the hill, being interrupted at the north by a fault. One other locality where the Golconda, judging from the stratigraphy, must be present, although the surface is so covered with residual material as to mask the outcrops, is in the eastern part of the quadrangle in the block bounded by faults 43, 46, and 47.

Lithologic Characters. Within the Dawson Springs quadrangle the Golconda is more of a shale formation than a limestone. In most places there are limestone layers, commonly more abundant in the lower part of the formation, interbedded with the shale. The limestone beds are mostly thin, a foot, more or less in thickness, although some attain a maximum thickness of

two and a half or three feet. The limestone beds are variable in character, most of them being crystalline in texture and light gray in color, but some are more compact and dark gray to brown. Near the center of the formation there are some more or less ferruginous limestone layers, one of which is conglomeratic locally. These beds weather into a yellow, porous material, often fossiliferous with somewhat worn fossils, making a fairly good horizon marker for the formation. The only locality where this particular part of the Golconda in the quadrangle is exposed occurs just north of Hart School in the most northern fault block containing the Golconda as a surface formation. This member, however, may be present in other parts of the quadrangle as in most localities only the upper portion of the formation is exposed, and where the entire thickness does come to the surface this particular bed may be covered with residual material.

The shale members of the Golconda are also variable in their lithologic characters. In many of the areas of exposure they are gray and thinly laminated, weathering to greenish and brown clays. In other localities they are darker and may be almost black and quite fissile. Some horizons, especially toward the top of the formation are more arenaceous, even containing some sand layers.

The most nearly complete exposed section of the Golconda in the quadrangle is in the side of the road to Dawson Springs, north of Crossroads Church. Here the entire formation is exposed with the exception of a few feet of the upper part which have been cut off by a fault. The detailed section of the part of the formation present is as follows:

Golconda Section North of Crossroads Church

	Feet	Inches
Shale, gray with thin limestone layers up to 8 inches in thickness	6	
Shale	2	
Sandstone, calcareous with shale partings	2	8
Limestone, gray, hard and compact	1	2
Shale, greenish, fissile	1	9
Limestone, brown		3
Shale, light gray	1	7
Limestone, gray, leached		6
Shale, gray to blue, ¾ inch sandstone layer in the middle	17	

Limestone, gray, crystalline, fossiliferous	1	10
Shale, gray, fissle	22	
	56	9

Thickness. The thickness of the Golconda formation in the Dawson Springs quadrangle varies between about 40 and 70 feet, but in most localities because of the weathering and slumping of the shaly beds, it is not possible to make any accurate measurements, and its thickness can only be approximately determined upon the basis of the interval between the overlying and underlying formations. The thicker part of the Golconda section appears to be in the more northern outcrops in the quadrangle.

Stratigraphic Relations. As has been stated already in connection with the discussion of the Cypress sandstone, there seems to be a condition of conformity between it and the overlying Golconda, exhibited in the gradual transition from sandstone to shale in the sedimentation. This condition seems to have prevailed throughout much of the Ohio Valley region in Kentucky and Illinois.

At a number of places in western Kentucky and southern Illinois a stratigraphic break is present in the section between the Golconda and the overlying Hardinsburg sandstone,[20] and the same general condition probably exists in the Dawson Springs quadrangle. The varying thickness of the Golconda suggests an unconformity between this formation and the overlying Hardinsburg, and the persistence of the more typical lower Golconda fauna rather than the higher faunas of the formation strengthens such an interpretation and at the same time helps to confirm the supposed conformable relationship of the Golconda with the underlying Cypress sandstone.

Paleontology. The Golconda limestone in Dawson Springs quadrangle is fossiliferous in most localities and a number of good collections of fossils have been obtained from the several outcrops. The Golconda in this general region of western Kentucky contains two rather distinct faunas. One is characterized by the more usual types of lower and middle Chester brachipods, bryozoans and the crinoid, *Pterotocrinus capitalis*, the most

[20] Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, p. 57.

characteristic lower Golconda fossil for this general region. The other is a molluscan fauna, characterized by numerous gastropods and some pelecypods, many of which are undescribed, and commonly occurs in the more sandy horizons towards the upper part of the section. A collection of the more usual types of Golconda species from the lower part of the formation in the isolated occurrence near Pleasant Grove Church has furnished the following species:

Golconda Fossils From Near Pleasant Grove Church

Pterotocrinus plates
Prenremites sp.
Rhombopora tabulata Ulrich
Fenestella exigua Ulrich
Archimedes terrebriformis Ulrich
Archimedes swallovanus (Hall)
Orthotetes kaskaskiensis (McChesney)
Productus ovatus Hall
Spirifer increbescens var. transversalis Hall
Spirifer sp.
Spiriferina transversa (McChesney)
Spiriferina spinosa (N. & P.)
Cliothyridina sublamellosa (Hall)
Composita trinuclea (Hall)
Nucula sp.
Myalina sp.
Deltodus sp.

Two other collections of this more usual type of Golconda fauna from exposures in the northern area of outcrop in fault block bounded by faults 8, 9, 12, and 14 have been studied. The first of these was collected from the roadside about one half mile north of Crossroads Church, and the second about 350 yards north of Hart School. In the following list the species of both of these collections are recorded, those indicated by an asterisk in column 1 being from the first locality, and those in column 2 are from the second locality.

Golconda Faunas From Near Crossroads Church

	No. 1	No. 2
Triplophyllum spinulosum (M.-E. & H.)	*	*
Pterotocrinus capitalis (Lyon)		*
Crinoid stems and plates	*	*
Pentremites sp.	*	*

Anisotrypa solida Ulrich		*
Rhombopora sp.	*	
Streblotrypa nickelsi Ulrich	*	
Fenestella cestriensis Ulrich		*
Archimedes terebriformis Ulrich		*
Archimedes swallowvanus (Hall)	*	
Crania chesterensis Miller & Gurley	*	
Diaphragmus elegans (N. & P.)	*	*
Productus sp.	*	
Pustula genevievensis Weller	*	
Spirifer increbescens var. transversalis Hall	*	*
Spirifer sp.	*	
Spiriferina spinosa (N. & P.)	*	
Girtyella indianensis (Girty)	*	
Camarophora explanata (McChesney)	*	
Eumeria vera (Hall)	*	
Cliothyridina sublamellosa (Hall)	*	*
Composita trinuclea (Hall)	*	*
Nucula sp.		*
Bembexia sp.		*
Sphaerodoma sp.	*	
Ostracods several species	*	

The best collections of the molluscan type of Golconda fauna were obtained from exposures north of Bainbridge Church in the block bounded by faults 37, 38, 39, and 40. Two good collections have been made, the first one from the roadside about three quarters of a mile north of the church and the other from a small glade-like exposure west of the road about one-half mile farther north. These two collections are recorded in a single list, the species indicated in column 1 being from the first locality, those from the second locality being in column 2.

Golconda Faunas From North of Bainbridge Church

	No. 1	No. 2
Pterotocrinus sp.		*
Crinoid stems		*
Rhombopora minor Ulrich		*
Fenestella sp.		*
Polypora sp.		*
Orthotestes kaskaskiensis (McChesney)		*
Productus sp.		*
Spirifer sp.	*	
Spiriferina spinosa (N. & P.)		*
Camarophora explanata (McChesney)		*

Cliothyridina sublamellosa (Hall)		*
Composita trinuclea (Hall)		*
Nucula randolphensis Weller		*
Leda chesterensis Weller		*
Leda sp.	*	
Conocardium sp.	*	*
Yoldia sp.		*
Bellerophon chesterensis Weller	*	*
Bucanopsis ornatus Weller		*
Ptychomphalus suttoni Weller (Mss.)		*
Ptychompalus recticulata Weller (Mss.)	*	*
Mourlonia trilineata Weller (Mss.)	*	*
Naticopsis sp.		*
Zygopleura sp.		*
Aclisina suttoni Weller (Mss.)	*	
Aclisina sp.	*	
Aclisina two species		*
Bulimorphia sp.		*
Cerithioides ? chesterensis Weller (Mss.)	*	
Orthoceras sp.	*	

Correlation. The correlation of the Golconda formation in the Dawson Springs quadrangle is established on paleontological evidence. The faunas recorded are characteristic of the lower portion of the typical Golconda, and both of the faunas are known from many localities in western Kentucky and southern Illinois.

Ulrich[21] has considered that only the upper part of the typical Golconda of the Ohio River section is present in this part of western Kentucky. He says that the lower part of the formation may be represented here by a considerable thickness (124 feet) of arenaceous beds, which in turn may be the equivalent of the upper part of the Cypress sandstone but the paleontological evidence shows that it is the lower portion of the Golconda formation that is most persistent from the Dawson Springs quadrangle to the Mississippi river.

Hardinsburg Sandstone

Name. The Hardinsburg sandstone succeeds the Golconda formation in the general section of the Chester Series in western Kentucky and southern Illinois. The formation was first named

[21] Ulrich, Mississippian Series in Western Kentucky, Kentucky Geological Survey, 1918, p. 73.

by Butts[22] from exposures at Hardinsburg in Breckinridge County, Kentucky. The formation thins to the west and is represented in the Mississippi River section by a thin, discontinuous sandstone layer which separates the lower and upper divisions of the Okaw limestone.[23] In the more southern counties of Illinois the formation is developed essentially as it is in western Kentucky.

Distribution. In the Dawson Springs quadrangle the Hardinsburg sandstone outcrops over a much greater area than any of the Chester formations so far discussed. With one exception only, it is associated with the Golconda in all the fault blocks where the latter is exposed, and in most cases it caps the hills in these fault blocks. In the same irregular faulted belt where the Golconda outcrops, the Hardinsburg is present in one block where no Golconda is exposed, this being the one immediately south of that in which Crossroads Church is located, and is bounded by faults 14, 15, 16, and 19.

In addition to the above mentioned outcrops the Hardinsburg is exposed in a number of fault blocks east of the belt in which the Golconda is exposed. Generally, in these more eastern exposures, the Hardinsburg is limited to the lower parts of the stream valleys and forms the beds of the streams for considerable distances, the dip of the rocks, in most cases, being such as to maintain the formation at the level of the valley floors.

Lithologic Characters. The Hardinsburg is widely variable throughout the extent of its outcrops in the Dawson Springs quadrangle. In the western part it is dominantly a shale formation, chiefly an arenaceous shale with some thin interbedded sandstone layers and with a more massive sandstone bed about 10 feet thick at the base, upward the arenaceous shale passes into the more calcareous shale of the lower Glen Dean. This phase of the formation is well exposed along the new Sandlick road near Curry in the block bounded by faults 14, 15, 16, and 19.

Farther east in the quadrangle the Hardinsburg becomes a more massive sandstone, the shale members existing more as partings between the sandstone beds. The sand of these sand-

[22]Charles Butts, Mississippian Series in Western Kentucky, Kentucky Geological Survey, 1918, p. 96.

[23]Stuart Weller, Geology of Hardin County, Illinois State Geological Survey, Bulletin 41, 1920, pp. 187-188.

stone layers is much like that of the Cypress and were it not for the stratigraphic position it would be impossible to distinguish between the two formations in many places. The shales are variable in character, as much so as those of the Golconda, but as a rule they are more arenaceous than those of either the Golconda or Glen Dean formations. Owing to the common shaly character of the Hardinsburg as well as the Glen Dean and Golconda formations, good exposures of this portion of the section, do not exist. In the southern part of the quadrangle the entire thickness of the Hardinsburg is nowhere completely exposed.

Thickness. The thickness of the Hardinsburg seems to exhibit considerable variation within the limits of the quadrangle and it has not been possible to make any accurate measurements. At Walche's cut in the Princeton quadrangle, Weller[24] has reported a thickness for the formation of 61 feet, 1 inch. The thickness in the Dawson Springs quadrangle approaches this in places while elsewhere it seems to be less, perhaps no more than 40 feet.

Stratigraphic Relations. The stratigraphic relation of the Hardinsburg with the underlying Golconda limestone is one of unconformity as has been pointed out in the discussion of that formation. At every locality where the contact between the Hardinsburg and Glen Dean can be seen, no break in the stratigraphic sequence can be detected, the arenaceous beds of the upper Hardinsburg passing almost insensibly into the lower shale members of the Glen Dean which commonly differ from the lower formation in being more calcareous in composition.

Paleontology. No fossils of any kind were obtained from the Hardinsburg sandstone in the Dawson Springs quadrangle, but elsewhere some fragmental plant remains have been reported.

Correlation. The correlation of the Hardinsburg of this map area is established by reason of its stratigraphic position between the Golconda and Glen Dean limestones, both definitely determined on paleontological grounds.

[24]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI. Vol. 10, 1923, p. 62.

Glen Dean Limestone

Name. The Glen Dean was named by Butts[25] from Breckinridge County, Kentucky, where the formation is well exposed along the railroad on both sides of Glen Dean. In a report on "Oil Investigation in Illinois in 1916," Brokaw[26] referred to a limestone occupying the stratigraphic position of the Glen Dean as the Sloans Valley formation, the name being taken from a locality in Pulaski County, Kentucky. This name had been used previously for field designation but the formation had never been properly described as such, and the stratigrophic succession at Sloans Valley has not been definitely established. In Breckinridge County the formation is distinctly limited above and below by the Tar Springs and Hardinsburg sandstones, and it is possible that the Sloans Valley beds include somewhat more strata than the exact equivalent of the Glen Dean of western Kentucky and southeastern Illinois.

Distribution. The distribution of the Glen Dean limestone in the southern part of the Dawson Springs quadrangle follows closely that of the underlying Hardinsburg sandstone. In the western part of the area containing this sandstone, the formation occurs in each of the fault blocks in which the Hardinsburg is exposed except those in which the Golconda outcrops; in no case do the Golconda and Glen Dean occur at the surface in the same fault block.

The Glen Dean also outcrops in the southwestern portion of the quadrangle in two fault blocks containing no Hardinsburg. These are the blocks bounded by faults 32, 38, 39, and 40 and by faults 19, 32, 34, and 35. In the southeastern part of the quadrangle the formation is again exposed in a number of fault blocks, unassociated with the underlying Hardinsburg. In each of the areas where the Glen Dean and underlying Hardinsburg occur together, it forms a relatively gentle slope along the streams, the beds of which are on the Hardinsburg. Elsewhere the Glen Dean forms the floors of rather broad valleys, as compared with those which are cut in the sandstones.

Lithologic Characters. The Glen Dean of this quadrangle is largely shale, exhibiting considerable variation in character

[25] Charles Butts, Mississippian Series in Western Kentucky, Kentucky Geological Survey, 1918, p. 97.

[26] A. D. Brokaw, Bulletin No. 35, Illinois State Geological Survey, 1916, p. 24.

from place to place throughout the areas of its exposure, with numerous examples of change in the section, the result of lateral gradation between shale and limestone. A somewhat generalized description of the formation is as follows: the lower portion, more than one-half, is dominantly shale and the upper portion more limestone, the limestone layers being separated by shale beds of varying thickness. In some localities the lower shaly portion contains limestone layers interbedded with the shale and in places a rather massive limestone layer three or four feet thick is present near the base. Wherever this limestone layer has been found it has been considered the base of the formation. In other localities where the basal limestone is absent it is impossible to draw a sharp line of demarcation between the Glen Dean and the underlying Hardinsburg. As a matter of fact, since the two formations represent one continuous epoch of sedimentation there is no physical basis of division except on the character of the shale, the gradual change from the arenaceous beds to the more calcareous ones. The upper part of the Glen Dean is likewise variable. In places the overlying Tar Springs sandstone rests upon the upper limestone beds, while elsewhere below the Tar Springs, a shale member from 7 to 10 feet thick is present. Locally, more especially in the western part of the quadrangle, a calcareous sandstone member about 9 feet thick is present about 25 feet below the top of the formation and in one exposure a thin limestone conglomerate, containing fossils of Glen Dean character, has been observed at the contact with the Tar Springs. In many exposures the shaly character of the formation as a whole is not conducive to good outcrops and some of the beds mentioned may be present although hidden by the residuum. In general the Glen Dean contains more limestone in the eastern part of the quadrangle.

The shales are variable in character. The lower beds are usually dark gray and rather fissile but in places they are darker, almost black and include some beds which are more green in color, resembling in this respect some of those in the Golconda. The higher shale layers interstratified with limestone are gray as a rule. The uppermost shale member, where observed, is black, carbonaceous, and finely laminated. The limestone layers are gray and usually crystalline, some beds being harder, denser, and

lighter in color. The individual beds are variable in thickness, ranging from a few inches to as much as two feet or more. Because of the shaly character of the beds, well exposed sections are rare. A complete section of the formation is exposed along the

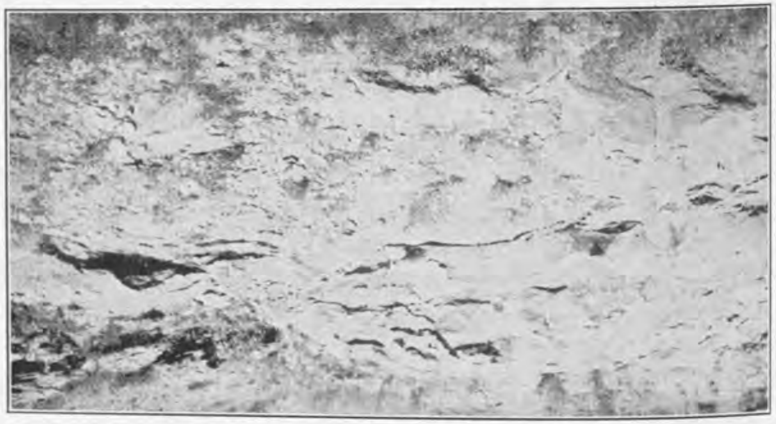


Fig. 10.—Glen Dean formation in cut of the old line of the L. & N. Railroad two and one-quarter miles south of Crofton.

New Sandlick road about one mile southeast of Crossroads Church where the following beds may be distinguished:

Glen Dean Section About One Mile Southeast of Crossroads Church

	Feet	Inches
Tar Springs sandstone		
Limestone, gray crystalline beds interstratified with shale layers	20	
Shale	4	5
Sandstone, somewhat calcareous	9	6
Shale, dark gray, fissile	42	
Limestone, gray, dense, compact	3	6
	79	5

Thickness. In the measured section just recorded there is a total thickness for the Glen Dean of 79 feet 5 inches. This thickness is considerably greater than the interval occupied by the formation between overlying and underlying formations in most parts of the quadrangle, the average being about 50 feet, in some sections being as little as 40 feet.

Stratigraphic Relations. The Glen Dean rests upon the underlying Hardinsburg sandstone with complete conformity. Where the basal limestone layer of the Glen Dean is present the shales just below it are more calcareous than those a little lower in the section, a gradual change in the character of sediments being exhibited before the deposition of the limestone. Where the limestone is not present, it is impossible to draw a sharp line of division between the two formations.

The contact between the Glen Dean and the overlying Tar Springs sandstone is sharper, the change from the calcareous sediments, limestone or shale, of the upper Glen Dean to the sandstone of the basal Tar Springs, being abrupt. The presence locally of a layer of limestone conglomerate at the top of the Glen Dean also suggests an unconformity between this formation and the overlying Tar Springs and this evidence together with the varying thickness of the Glen Dean, indicates the existence of an interval of erosion preceding the deposition of the Tar Springs sandstone. All of these facts, taken together, seem to be sufficient proof of an unconformable contact between the two formations.

Paleontology. In certain localities the Glen Dean is abundantly fossiliferous, and especially where the upper limestones and shales have been weathered, the fossils may be found scattered over the surface. One of the most diagnostic species in the formation is the bryozoan, *Prismopora serrulata,* which is not found in every exposure in the Dawson Springs quadrangle and is less common here than in some other regions. *Pentremites spicatus, Pentremites brevis, Pterotocrinus depressus, and Chilotrypa hispida,* all characteristic Glen Dean fossils, have been collected in the quadrangle.

An excellent collection of silicified fossils from the upper part of the formation was secured from an outcrop along the roadside, in the more southern Glen Dean exposure in the fault block bounded by faults 19, 32, 34, and 35, about one and one-half miles southeast of Poole School, and the following species have been recognized.

Glen Dean Fauna From Southeast of Poole School

Triplophyllum spinulosum (M.-E. & H.)
Agassizocrinus conicus Owen & Shumard

Eupachycrinus boydii (M. & W.)
Pentremites brevis Ulrich
Archimedes swallovanus Hall
Productus ovatus Hall
Diaphragmus elegans (N. & P.)
Camarophora explanata (McChesney)
Dielasma cf. shumardanum (Miller)
Girtyella indianensis (Girty)
Spirifer increbescens Hall
Spirifer sp.
Spiriferina spinosa (N. & P.)
Recticularia setigera Hall
Eumetria vera (Hall)
Cliothyridina sublamellosa (Hall)
Composita trinuclea (Hall)
Nucula sp.
Ptychomphalus dawsonensis Weller (Mss.)

Another smaller collection was gathered at a locality along the first stream bed east of the road leading south from Consolation School in the southeast rectangle.

Fossils From the Glen Dean South of Consolation School

Eupachycrinus sp.
Pterotocrinus two species
Crinoid stems, plates and spines
Pentremites spicatus Ulrich
Fistulipora excelens Ulrich
Fenestella sp.
Archimedes swallovanus Hall
Archimedes terebriformis Ulrich
Rhombopora tabulata Ulrich
Rhombopora minor Ulrich
Spirifer increbescens Hall

The only locality where the characteristic *Prismopora serrulata* is known to occur as a common species in the fauna is in the Glen Dean outcrop occupying the saddle in the fault block bounded by faults 43, 46, and 47, about one and one-half miles northeast of Palestine School in the southeast part of the quadrangle. Another unusual feature of this fauna is the presence of a species of the brachiopod genus, *Chonetes,* a fossil rare in the Chester of Kentucky and Illinois except for *Chonetes illinoisensis* in the Paint Creek, although Butts reports it as abundant in the Glen Dean of Alabama. The only locality in the more western part of Kentucky or in southern Illinois where a species of this genus is known in the Glen Dean is in the Vienna quadrangle, Illinois. At this locality in the Dawson Springs quadrangle the upper shale and limestone members of the Glen Dean have decomposed leaving the well preserved fossils scattered over the surface of the ground. The species obtained from this locality are given in the list below.

Glen Dean Fauna From One and One-half Miles Northeast of Palestine School

Triplophyllum spinulosum (M.-E. & H.)
Agassizocrinus sp.
Eupachycrinus sp.
Onychocrinus sp.
Pentremites symmetricus Hall
Fistulipora excelens Ulrich
Anisotrypa macropora McFarlan (Mss.)
Anisotrypa solida Ulrich
Eridopora punctifera Ulrich
Tabulipora rudis (Ulrich)
Tabulipora ramosa (Ulrich)
Rhombopora tabulata Ulrich
Chilotrypa hispida Ulrich
Prismopora serrulata Ulrich
Fenestelle cestriensis Ulrich
Fenestella elevatipora Ulrich
Archimedes meekanus (Hall)
Archimedes terrebriformis Ulrich
Archimedes swallovanus Hall
Polypora spinulifera Ulrich
Polypora two species
Orthotetes kaskaskiensis (McChesney)
Chonetes cf. chesterensis Weller
Productus inflatus McChesney
Diaphragmus elegans (N. & P.)
Spirifer increbescens Hall
Spiriferina spinosa (N. & P.)
Eumetria vera (Hall)
Cliothyridina subamellosa (Hall)
Composita trinuclea (Hall)
Leda sp.

One other important collection was obtained from a cut along the old line of the Louisville and Nashville railroad about

two and one-quarter miles south of Crofton, Kentucky, about one mile east of the boundary line of the Dawson Springs quadrangle.

Fauna From the Glen Dean Limestone About Two and One-quarter Miles South of Crofton, Kentucky

Triplophyllum spinulosum (M.-E. & H.)
Amplexus sp.
Pterotocrinus depressus Lyon and Cassiday
Crinoid plates and stems
Pentremites brevis Ulrich
Pentremites canalis Ulrich
Fistulipora excelens Ulrich
Fistulipora montifera McFarlan (Mss.)
Tabulipora tuberculata (Prout)
Batostomella irregularis McFarlan (Mss.)
Fenestella serratula Ulrich
Fenestella tenax Ulrich
Fenestella several species
Archimedes terrebriformis Ulrich
Archimedes swallovanus Hall
Archimedes meekanus (Hall)
Polypora corticosa Ulrich
Polypora approximata Ulrich
Rhombopora minor Ulrich
Streblotrypa nickelsi Ulrich
Diaphragmus elegans (N. & P.)
Dielasma cf. shumardanum (Miller)
Spiriferina sp.
Spirifer increbescens Hall
Spirifer sp.
Camarophora explanata (McChesney)
Eumetria vera (Hall)
Cliothyridina sublamellosa (Hall)
Composita trinuclea (Hall)
Composita cf. subquadrata (Hall)
Bembexia croftonensis Weller (Mss.)
Ostracods several species

Correlation. The correlation of the Glen Dean is based on both paleontological and stratigraphic evidences. The presence of the characteristic Glen Dean fossils such as *Pentremites brevis, Pentremites spicatus, Pterotocrinus depressus, Prismopora serrulata, Chilotrypa hispida,* and other species of bryozoans is evidence for such correlation. Furthermore the formation has been mapped completely across southern Illinois and western Kentucky as far as the Dawson Springs quadrangle and has been shown to be continuous, although this detailed mapping has not been connected up with the type expression in Breckinridge County.

Tar Springs Sandstone

Name. The Tar Springs sandstone was named by Owen[27] from exposures in Breckinridge County, Kentucky, where the formation overlies the limestones and shales of the typical Glen Dean. A common feature characteristic of the sandstone in that region is the presence of springs whose waters contain a considerable amount of bitumen. Such springs are spoken of locally as "tar springs" and as long ago as 1859 this name was given to the sandstone from which many of the springs issue. The name has since been extended to include the sandstone formation overlying the Glen Dean throughout western Kentucky and southern Illinois.

Distribution. Because of its greater thickness and the presence of more massive and more resistant sandstone beds, the Tar Springs in the Dawson Springs quadrangle is the surface formation over much larger areas than any other Chester formation. Beginning in the southwestern corner of the west central rectangle this formation occupies a belt, more or less discontinuous by reason of the faulting, extending in a southeast and easterly direction across the quadrangle. Throughout most of this belt it is the surface formation of the upland areas, but in some of the fault blocks it is the only formation exposed. Where it occupies the upland areas it breaks away from them with steep or precipitous slopes which are underlain by more gentle slopes due to the less resistant Glen Dean limestone and Hardinsburg sandstone. In a few localities the Tar Springs occurs beneath higher Chester formations as relatively steep slopes below the more gentle slopes of the overlying beds. Elsewhere the top of the formation occurs in the floor of some streams.

Lithologic Characters. The Tar Springs is dominantly quartz sandstone. In texture it is similar to the other Chester

[27]D. D. Owen, 2nd. Report of the Kentucky Geological Survey, Vol. 2, 1857, pp. 86-87.

sandstones of the area, being rather fine grained and not as coarse perhaps, as the Bethel sandstone. As a rule it is light yellow in color varying to brownish in many places. It is more massive, in general, than any other sandstone of the Chester

Fig. 11.—Steeply dipping Tar Springs sandstone in a cut of the old line of the L. and N. railroad south of Crofton, Kentucky.

Series with the exception of the Palestine and locally of some beds of the Bethel, and its characteristic topographic expression is exhibited in the bluffs and cliffs along the stream courses which have cut into or through it.

The lower part of the formation consists of massive sandstone ledges, some of which are separated by thin shale layers. This part of the formation is succeeded by a series of thinner beds of yellow sandstone interbedded with more and thicker shale members, while the upper part again becomes more massively bedded.

Where a considerable part of the formation is exposed it is impossible to mistake it for any other one of the Chester sandstones because of its much greater thickness and its bluff forming habit. Parts of the Palestine are as massive but the color is usually different. Where only a portion of the Tar Springs is exposed in a fault block with neither overlying nor underlying formation present, the problem of identification becomes more difficult. Examples of such a situation are to be found in the

fault blocks formed by faults 5, 7, and 8 and by faults 12, 13, and 19.

In the Princeton quadrangle a horizon of carbonaceous shales, which become an impure coal in places, is present in the

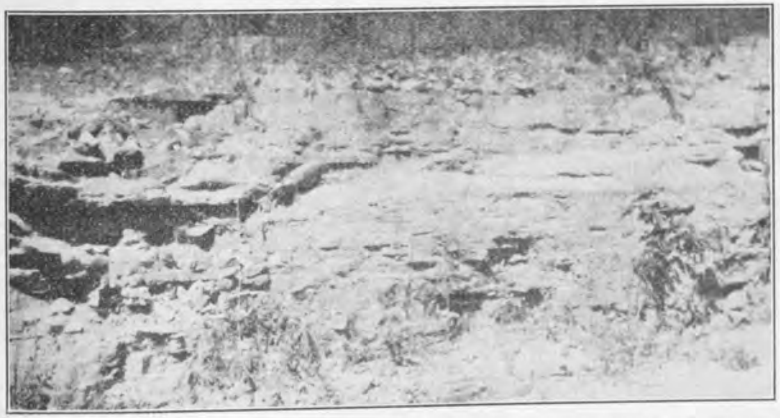


Fig. 12.—Portion of the Tar Springs showing thinner beds, about one mile north of Bainbridge Church.

middle shaly portion of the formation above the massive basal beds[28]. This carbonaceous bed is somewhat persistent throughout western Kentucky and southern Illinois but has not been observed anywhere in the Dawson Springs quadrangle, although it may be present, because the more shaly portions of the formation are commonly covered with broken blocks of sandstone, slumped down from the overlying massive sandstone ledges and unless favorable exposures are present the shaly portions of the formation are hidden. In view of the fact that no railroad or road cuts exist in the part of the quadrangle where the Tar Springs is the surface formation no really good sections are available for study.

An incomplete section of the Tar Springs is exposed along the road about one mile north of Bainbridge Church in the southwest part of the south central rectangle. The section is not complete, the basal portion of the formation being faulted against the Hardinsburg sandstone and some of the higher beds

[28]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, p. 69.

being removed by erosion. For that part of the formation exposed, the following succession of beds has been obtained:

Section of Tar Springs Sandstone One Mile North of Bainbridge Church

	Feet	Inches
Sandstone, yellowish and rather massively bedded	30	
Sandstone, yellowish, thin bedded	8	8
Shale		2
Sandstone, yellow, beds 1½ inches thick or less	2	2
Sandstone, brown, beds 1½ to 3 inches thick	5	1
Sandstone, yellowish, massive	4	8
Sandstone, yellow, beds up to 8 inches in thickness	9	6
Sandstone and shale interbedded	30	
Sandstone, yellow, massive	1	4
Sandstone, brownish-yellow, interbedded with shale layers	43	0
	134	7

Thickness. The Tar Springs sandstone is much the thickest formation of the Chester Series in the Dawson Springs quadrangle, attaining a maximum of more than 200 feet. The top and bottom of the formation, exhibiting contacts with overlying and underlying beds, are not exposed anywhere in the quadrangle in the same fault block in a situation to permit the accurate measurement of the entire formation, but in one locality just northwest of Palestine School in the southeast rectangle nearly the entire thickness must be present in the interval between the fault

Fig. 13.—More massive sandstone layer in the Tar Springs north of Bainbridge Church.

at the base of the Tar Springs and the base of the overlying Vienna limestone. The formation seems to become a little thinner as it is traced eastward across the quadrangle.

Stratigraphic Relations. The abrupt change in the character of the sediment from the calcareous shales and limestones of the upper Glen Dean to the sandstones of the basal Tar Springs, the presence of the limestone conglomerate bed at the contact between the two formations, and the variable thickness of the Glen Dean are evidences of an unconformity between the two formations.

The stratigraphic relation of the Tar Springs with the overlying Vienna in the Dawson Springs quadrangle cannot be certainly established since no good exposures of the actual contact between the two formations have been observed. The sandstone members of the upper Tar Springs become thinner with a corresponding increase in the thickness of the interbedded shale layers, and these beds appear to merge into the shales of the overlying Vienna so that there seems to be no interruption in the sedimentary record and consequently no unconformity.

Paleontology. No fossils of any kind have been observed in the Tar Springs in the Dawson Springs quadrangle although fragmental plant remains may be looked for and probably do exist.

Correlation. The correlation of the Tar Springs sandstone in this quadrangle can be based only on its stratigraphic position above the Glen Dean limestone, the identity of which has been surely established by reason of the peculiar assemblage of fossils contained in it.

Vienna, Waltersburg, and Menard Formations

In actual field practice it has been found to be more practicable to combine the Vienna limestone, Waltersburg sandstone, and Menard limestone in the Dawson Springs quadrangle and to map the three formations as a unit rather than separately. This practice has been followed because of the limited thickness of the two lower formations mentioned, especially in the eastern part of the quadrangle where they are much thinner than in the more western portion.

Names. Both the Vienna and Waltersburg formations were named by Weller,[29] the Vienna from exposures in the vicinity of Vienna, Johnson County, Illinois, and the Waltersburg from outcrops in Pope County, Illinois. The Vienna has been recognized as a persistent unit of the Chester Series over much of southern Illinois and western Kentucky. In the Dawson Springs quadrangle it begins to thin rapidly toward the east and farther east it is impossible to differentiate it among the upper Chester formations.[30] The Waltersburg occurs persistently across southern Illinois and as far southeast as the Princeton quadrangle in Kentucky, but in the Dawson Springs quadrangle it thins rapidly toward the east and, like the Vienna, disappears as a recognizable unit in the Chester Series.

The Menard limestone was also named by Weller[31] from the exposures in Randolph County, Illinois, just north of the city of Chester. This formation has been mapped in detail across Illinois and into Kentucky and is one of the more important and more persistent upper Chester formations.

Distribution. The exposures of these three formations are limited in number in the Dawson Springs quadrangle, occurring in only a few of the fault blocks near the northern part of the outcrop of the Chester formations. Beginning in the southwestern corner of the west central rectangle and extending a little south of east the outcrop appears at the surface in a number of fault blocks forming a discontinuous belt almost across the quadrangle.

The only exposure of the typical Vienna which has been observed is in the small fault block bounded by faults 8, 9, 10, and 12, near Sandlick road about two miles east of Crossroads Church. Here the strata have been so disturbed that they are now almost vertical in position, exposing nearly the whole of the Vienna, Waltersburg, Menard, and Palestine formations. With the exception of the fault block bounded by faults 4, 5, and 7, where only the Menard is exposed, the three formations are associated in all the other outcrops in the quadrangle. The areas

[29]Stuart Weller, The Chester Series in Illinois, The Journal of Geology, Vol. 28, 1920, pp. 396-398.

[30]J. Marvin Weller, Geology of Edmonson County, Kentucky Geological Survey, Series VI, Vol. 28, 1927. P. 148.

[31]Stuart Weller, Transactions of the Illinois Academy of Science, Vol. 6, 1914, p. 128: also, Illinois State Geological Survey, Monograph 1, 1914, p 28.

where the three formations have the greatest areal extent are in the four following fault blocks: (1) in the large block near the northeast part of the southwest rectangle and the adjacent part of the southwest rectangle, (2) the block formed by faults 4, 8, 11, 12, 13, and 19, (3) in the south central rectangle in fault block bounded by faults 4, 26, 27, 29, and 32, and (4) in the southeast rectangle in fault block bounded by faults 30 and 43. A few smaller areas of outcrop occur in some of the other fault blocks in the quadrangle.

Lithologic Characters of the Vienna. The Vienna in the western part of the quadrangle consists of an interbedded shale and cherty limestone member with overlying shale beds. The chert occurs in thin layers from one to three inches thick which break up into more or less cubical fragments equal in size to the thickness of the chert layers. In places the limestones are siliceous, thinly bedded and yellow and weather into a yellow siliceous, porous material. These characteristic lithologic features serve to identify the formation. Above the siliceous limestone beds there is a series of thinly laminated shales, varying in color from dark to light gray.

Farther east in the quadrangle the cherty limestone member is lacking and the entire thickness of strata which can be referred to the Vienna consists of only 12 to 15 feet of bluish gray shale with a few one-inch thick layers of leached, yellowish, siliceous limestone.

Lithologic Characters of the Waltersburg. At the excellent exposure of the Waltersburg sandstone in Walche's cut in the Princeton quadrangle, the formation consists of two sandstone layers each one foot four inches thick separated by four feet of black shale.[32] At one locality in the Dawson Springs quadrangle, in the outcrop in the small fault block near the Sandlick road where the beds are essentially vertical in position, the Waltersburg displays a succession similar to that in the Walche's cut section but is thinner, being only about three feet in thickness. The shales are almost black in color and the sandstone reddish brown. In the eastern part of the quadrangle at the exposure about three-quarters of a mile north of Palestine School, one bed of reddish brown sandstone, four inches thick, is present

[32]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, p. 75.

below the Menard limestone, and seems to represent the Waltersburg in this part of the quadrangle.

These conditions indicate a rapid thinning of both the Waltersburg and Vienna in an eastward direction and it is doubtful if these formations can be differentiated from the Menard farther east.

Lithologic Characters of the Menard. The Menard is more of a limestone formation in the western than in the eastern portion of the quadrangle. In the more western area the lower part of the formation contains considerable amounts of shale interbedded with the limestone, with more massive limestone beds in the upper part. Farther east the formation becomes more dominantly shale and decreases somewhat in thickness. In the more eastern part of the quadrangle the lower 10 feet of the Menard are shale which is followed by interbedded limestone and shale layers with the upper part again shale. The shale members are usually gray in color and rather thinly laminated. The limestone beds are commonly gray, hard, and compact with some yellowish, crystalline layers near the base of the interbedded limestone and shale zone.

Thickness. Two of these formations, the Vienna and Waltersburg, exhibit greater progressive thinning in an eastward direction than any other of the formations in the Chester Series. In its most western exposure in the quadrangle, the Vienna is approximately 40 feet thick, the section consisting of about 15 feet of cherty limestone below and an upper shale member. In the more eastern outcrops north of Palestine School the entire formation consists of 12 to 15 feet of shale beds.

The Waltersburg sandstone, consisting of about three feet of shale and sandstone in the west, thins to four inches of sandstone in the same outcrop where the Vienna is exposed. In the area between faults 30 and 43 no beds referable to the Waltersburg have been observed and consequently it has been impossible to distinguish between the Vienna and Menard in the lower shale portion of this part of the section.

The Menard retains a more uniform thickness across the quadrangle, although it also thins toward the east. In the western section the thickness is about 80 feet, much of which is limestone but in the more eastern exposures the total thickness is

not more than 55 or 60 feet, including a larger proportion of shale than of limestone. Because of the shaly character of the formation in this region, the outcrops commonly are covered with talus to such a degree that it is not possible to make accurate measurements of the sections. At the exposure north of Palestine School the thickness of the Menard is approximately 60 feet, the lower 10 feet of which is gray shale, which is followed by about 35 feet of interstratified shale and limestone, with a 15-foot shale member at the top.

Stratigraphic Relations. There is no reason to believe that any unconformity exists between the Tar Springs sandstone and the formations which are here grouped together, neither is there any interruption of sedimentation between these formations themselves.

Between the Menard limestone and the overlying Palestine sandstone there is evidence suggesting an interruption of the sedimentary record. The change from the calcareous sediments of the upper Menard to the sandstone of the Palestine is abrupt, and the varying thickness of the Menard may have been caused by an interval of erosion before the deposition of the Palestine. An undoubted unconformity exists between these two formations in southern Illinois and the same condition seems to exist in the more western part of Kentucky, and perhaps extends as far east as the Dawson Springs quadrangle.

Paleontology. Some of the shaly beds of the Vienna are sparingly fossiliferous with specimens too fragmental to be surely identified. No fossils have been observed in the Waltersburg at the few localities where it occurs at the surface, although it is possible that fragmental plant remains may be present in the formation in places. The Menard is abundantly fossiliferous in certain horizons, the best specimens being obtained from the shaly layers between the limestone beds. The limestone members are themselves fossiliferous as a rule, but for the most part the fossils have not been preserved in a condition suitable for identification. Most of the species are the more usual long range Chester types but some are more characteristic of the Menard. The more notable changes in the fauna are in the much increased size of *Spirifer increbescens* and the development of *Composita subquadrata* rather than *Composita trinuclea* which is

present in all the lower Chester faunas. These two species of the genus Composita, seem to form a complete genetic series, all gradations being present in the faunas of the Chester Series with the shells in the higher Chester formations assuming more typically the characteristics of *Composita subquadrata.*

Pterotocrinus menardensis, one of the characteristic Menard fossile farther west in Kentucky and in southern Illinois, has not been certainly identified from any of the collections from the Dawson Springs quadrangle. The same is true for *Sulcatopinna missouriensis,* but this does not mean that they do not exist here and more complete collections may disclose them. An undescribed species of the bryozoan genus, *Tabulipora,* occurring in large subglobular and subhemispherical masses, formed by the superimposition of layer upon layer, was collected from the exposures in fault block between faults 30 and 43. This species has been recognized in the Menard at other localities and may be limited to this formation.

The collections secured from the Menard are not as complete and do not contain as many species as do those from some of the other limestones in this region. One of the more typical Menard faunas was collected from outcrops about three-quarters of a mile south of Ruth in the southwestern corner of the west central rectangle, and the following species have been identified:

Menard Fossils From South of Ruth

Pterotocrinus sp.
Agassizocrinus sp.
Crinoid plates and stems
Fenestella tenax Ulrich
Fenestella sp.
Orthotetes kaskaskiensis (McChesney)
Productus ovatus Hall
Diaphragmus elegans (N. & P.)
Spirifer increbescens Hall
Spirifer sp.
Girtyella brevilobita (Swallow)
Cliothyridina sublamellosa (Hall)
Composita subquadrata (Hall)
Bellerophon sp.
Phillipsia sp.

Two collections were secured from exposures in the fault block between faults 30 and 43. One of these is small containing only a few species and was made along the road leading down to Wallace Fork, about three and one-half miles west of Crofton, Kentucky.

Menard Fossils From West of Crofton

Triplophyllum spinulosum (M.-E. & H.)
Agassizocrinus sp.
Pterotocrinus sp.
Crinoid stems
Pentremites sp.
Spirifer increbescens Hall

The second collection is from outcrops along the south side of the same hill, about one-quarter of a mile west of the road leading down to Dripping Springs Branch, one and three-quarter miles north of Palestine School, and has furnished the following species:

Menard Fauna From North of Palestine School

Triplophyllum spinulosum (M.-E. & H.)
Crinoid stems
Pentremites sp.
Fistulipora bucheri McFarlan (Mss.)
Tabulipora sp.
Archimedes swallovanus (Hall)
Lyropora sp.
Camarophora explanata (McChesney)
Productus cf. inflatus McChesney
Diaphragmus elegans (N. & P.)
Girtyella indianensis (Girty)
Spirifer increbescens Hall
Spirifer sp.
Eumetria vera (Hall)
Cliothyridina sublamellosa (Hall)
Composita subquadrata (Hall)

Correlation. The correlation of the Vienna, Waltersburg, and Menard has been established by the actual tracing of the formations from the region further west where they are more typically developed, by their stratigraphic position between the massive Palestine sandstone above and the Tar Springs below, and by the recognition of the Menard faunas. The existence of

the Vienna limestone with its highly characteristic and peculiar lithology, lying above the massive Tar Springs sandstone is an important factor in the correlation.

Some doubt exists as to the identity of the exposures mapped as the Vienna-Waltersburg-Menard in the eastern part of the quadrangle between faults 30 and 43. Careful search has disclosed no diagnostic fossils unless the massive subglobular bryozoan, *Tabulipora sp.*, and the bryoboan, *Fistulipora bucheri* can be considered as such. The latter of these species was originally described from the Menard limestone and there is no record of its having been found in any other formation. No beds referrable to the Waltersburg are present in any of the outcrops but it is possible that the lithologic phase representing this formation may have terminated completely here since only four inches of the characteristic sandstone exist a mile or two farther south. The beds in question are overlain and underlain by massive sandstones which resemble only the Palestine and Tar Springs formations, no other Chester sandstones being either as thick or as massive as these two formations in this part of western Kentucky.

PALESTINE SANDSTONE

Name. The Palestine sandstone was named by Weller[33] from exposures in Palestine Township, Randolph County, Illinois. The formation extends across southern Illinois between the Mississippi and Ohio rivers with essentially the same thickness, being unlike the earlier Chester sandstones in this respect, all of which thin notably either in a westward or eastward direction.[34] Weller's detailed mapping in western Kentucky has shown that the formation is continuous as far as the eastern side of the Princeton quadrangle with essentially the same thickness, and the same situation has been found to prevail in the Dawson Springs quadrangle. Farther east it becomes thinner and its differentiation from the other members of the upper Chester becomes impracticable.

Distribution. In the Dawson Springs quadrangle the Palestine is the surface formation in only a few of the fault blocks

[33]Stuart Weller, Trans. Ill. Acad. Sci., 1914, Vol. 6, p. 128; also, Ill. Geol. Survey, Monograph 1, 1914, p. 29.
[34]Stuart Weller, Geology of the Golconda Quadrangle, Kentucky Geological Survey, Series VI, Vol. 4, 1921, p. 88.

along the northern edge of the area occupied by the Mississippian. The most western exposure in the quadrangle is in the fault block bounded by faults 4, 5, and 7 where the beds are steeply inclined toward the southeast. (Fig. 14) East of this locality its

Fig. 14.—Steeply dipping beds of the Palestine sandstone north of Crossroads Church.

next appearance is in fault block bounded by faults 8, 9, 10, and 12, in the rather narrow belt of vertical strata. In the large block surrounded by faults 4, 8, 11, 12, 13, and 19 the Palestine caps the hill west of Piny Creek and occurs in a narrow sinuous outcrop in the hillsides throughout the remainder of the block. In the block bounded by faults 4, 27, 28, and 29 the formation is found under similar conditions. In the small block just northeast of the one last named, it is the capping formation of the hill along Buttermilk Road for a distance of about three-quarters of a mile. The easternmost exposures are at the eastern edge of the quadrangle north of fault No. 43. Here the Palestine outcrops have a much greater areal extent than in any of the other exposures in the quadrangle, being the surface formation over a considerable area of level land.

Lithologic Characters. In the Dawson Springs quadrangle the Palestine sandstone is usually a brown to yellowish quartz sandstone, in places slightly pinkish in color. The texture is moderately fine and uniform, similar to that of the Tar Springs and other Chester sandstones. Its chief difference from the Tar Springs is in color, the latter being usually a more yellow sand-

stone. With the exception of the Tar Springs the Palestine is the thickest and most massive of the Chester sandstones of this area.

The massive layers of the formation attain a thickness in places of from 10 to 12 feet. In other localities the formation is

Fig. 15.—Bluff formed by the massive Palestine sandstone along Dripping Springs Branch, southeast part of the quadrangle.

equally as massive but with the individual beds thinner, 3 to 5 feet thick. Elsewhere the formation is more thinly bedded, individual layers being a foot, more or less, in thickness. The percentage of shale in the formation is low as compared with some of the other Chester sandstones of the region, although in places, considerable amounts of shale do occur as thin layers between the sandstone beds.

In many exposures the Palestine is so similar to other sandstones of the Chester Series, that only its stratigraphic position with relation to the limestones of the series serves to establish its identity.

Thickness. Next to the Tar Springs the Palestine is the thickest as well as the most massive sandstone formation of the Chester Series in the Dawson Springs quadrangle. When traced eastward across the quadrangle it exhibits a progressive increase in thickness and a development of more massive facies. In the western part of the quadrangle the average thickness is about 60 feet. In the eastern exposures this thickness has increased to a minimum of 100 feet or more.

Stratigraphic Relations. In discussing the stratigraphic relation of the Menard limestone to the overlying Palestine, facts have been presented which seem to establish the existence of an unconformity between the two formations, but in passing from the Palestine to the overlying Clore limestone, there seems to be no interruption in the sedimentary record, although actual contacts between the two formations have not been observed anywhere in the quadrangle.

Paleontology. Like the other Chester sandstones generally, the Palestine is only sparsely fossiliferous and no fossils of any kind have been met with in the Dawson Springs quadrangle. Fragmentary remains of plants, especially the trunks of *Lepidodendron*, have been collected from the formation in some localities and such fossils may be expected in this quadrangle, but if ever they are found in this sandstone they will not be of diagnostic value as horizon markers for the same species seem to recur in the several sandstones of the series.

Correlation. The correlation of the Palestine is based entirely on its stratigraphic position above the Menard limestone and below the higher Chester formations, a stratigraphic position occupied by a similar sandstone throughout the extent of the Chester outcrops in western Kentucky and southern Illinois. The greater thickness and more massive character of the formation also help to distinguish it from all except the Tar Springs sandstone and here the difference in color and the smaller amount of shale are of diagnostic value.

Clore, Degonia, and Kinkaid Formations

As with the Vienna, Waltersburg, and Menard formations, so the Clore limestone, Degonia sandstone, and Kinkaid limestone have been considered as a single unit in the mapping of the Dawson Springs quadrangle, the slight development of the Degonia sandstone making it impracticable to separate the three formations.

Name. The Clore limestone was named by Weller[35] from exposures in Randolph County, Illinois, and at the time it was described this formation was believed to be the highest formation of the Chester Series. Later field studies have brought out the

[35]Stuart Weller, Trans. Ill. Acad. Sci., Vol. 6, 1914, p. 129; also, Ill. State Geol. Surv. Monograph 1, 1914, p. 29.

fact that the section contains two still higher units, the Degonia sandstone and the Kinkaid limestone. The Clore can be differentiated across southern Illinois and extends into western Kentucky as far east and beyond the Dawson Springs quadrangle, but the formation as such has not been recognized in Edmonson County, Kentucky [36] The Degonia sandstone and Kinkaid limestone were also named by Weller[37] from outcrops in Jackson County, Illinois, their existence as the two highest members of the Chester Series being established by J. Marvin Weller.

Distribution. Strata representing these three Chester formations are limited in their distribution in the Dawson Springs quadrangle and in many of the exposures only the upper part of the Kinkaid is present. The most western outcrops are along the course of Montgomery Creek and west of Mount Hebron School in the western part of the west central rectangle where only the Kinkaid is exposed and the northeasterly dip carries the beds below the surface in a short distance down stream. A similar exposure along a small stream exists in the fault block bounded by faults 4, 5, 6, and 8. In the large fault block southeast of the one last mentioned this series of strata appears as a narrow belt above the Palestine sandstone, the thickness of the formations being variable here because of the pre-Pennsylvanian erosion which removed varying amounts of material before the Pennsylvanian sedimentation.

In the block bounded by faults 4, 27, 28, and 29 these highest Chester beds are exposed at the surface over a considerable area, a sandstone bed, doubtless the equivalent of the Degonia capping the upland areas with the Clore beneath, all of the Kinkaid apparently having been removed by erosion.

These formations are exposed farther east in two areas of considerable extent. In the block bounded by faults 26, 27, and 30 they are present above the bluff of Palestine sandstone with a few small remnants of Pennsylvanian on the highest hill tops. In the southern part of the block bounded by faults 20, 24, and 25 these formations lie almost horizontally but in the northern edge of this same block they are tilted at a high angle and carried below the surface by the deformation due to faulting.

[36] J. Marvin Weller, Geology of Edmonson County, Kentucky Geol. Survey, Series VI, Vol. 28, 1927. P. 148.

[37] Stuart Weller, The Chester Series in Illinois, Journal of Geology, Vol. 28, 1920, pp. 403-405.

Other smaller outcrops are present elsewhere in some of the fault blocks in the eastern part of the area of Mississippian exposure (see Plate 1 for details), where the formation exposed is mostly the Kinkaid, the strata commonly dipping steeply away from the fault planes.

Fig. 16.—Details of the Clore in the railroad cut north of Crofton.

Lithologic Characters of the Clore. The Clore formation is composed of varying proportions of limestone and shale, with the shale predominating in most places. In most outcrops the shales have disintegrated through weathering to such an extent that the exposures are largely covered by the accumulation of talus on the slopes, making it difficult or impossible to determine in detail the succession of strata. No really satisfactory exposures have been met with in the Dawson Springs quadrangle, but in a cut along the Louisville and Nashville railroad about one mile north of Crofton and one mile east of the Dawson Springs quadrangle, the beds of the formation are well exposed.

At this locality nearly the whole thickness of the Clore is exposed. The lower portion, about 15 feet, is largely shale with lesser amounts of limestone occurring as thin layers interbedded in the shale. The limestone layers in the lower part of this zone are from one to three inches thick, increasing in thickness toward the upper part of the zone, attaining a maximum thickness of six to eight inches. Locally some of these limestone beds

are cherty. This lower zone is succeeded by about 20 feet of gray shale and the upper part of the formation, about 15 feet thick, is more largely limestone.

Most of the shales in the Clore are gray in color and rather thinly bedded. The limestones vary from light to dark gray,

Fig. 17.—Limestone layer near the top of the middle shale zone of the Clore, north of Crofton.

and, as a rule, become lighter upon weathering. They are generally hard and more or less brittle, weathering with smooth rounded surfaces.

Lithologic Characters of the Degonia. The Degonia sandstone is similar to other Chester sandstones in the Chester section in this area. It is a fine grained, thinly bedded quartz sandstone, in which locally the lower part contains some shaly partings.

Lithologic Characters of the Kinkaid. The Kinkaid formation is composed chiefly of limestone layers with lesser amounts of shale. As a rule the limestone beds are more massive than those of the Clore, the formation as a whole being more like the Menard than any other of the Chester limestones. The limestone and shale beds vary in thickness and lithologic characters.

Many of the limestone beds are gray, hard, and compact, and break with a splintery fracture and weather with smooth rounded surfaces. Some beds however are more crystalline in texture and weather irregularly. In the higher part of the formation in a number of exposures, both in the western and eastern parts of the quadrangle certain limestone beds are present,

usually two in number, which are gray on freshly broken surfaces and become yellow upon weathering. These beds are not present in all outcrops because of the varying amount of pre-Pennsylvanian erosion, but where such erosion was not carried too far they seem to be persistent. Some of the limestone beds

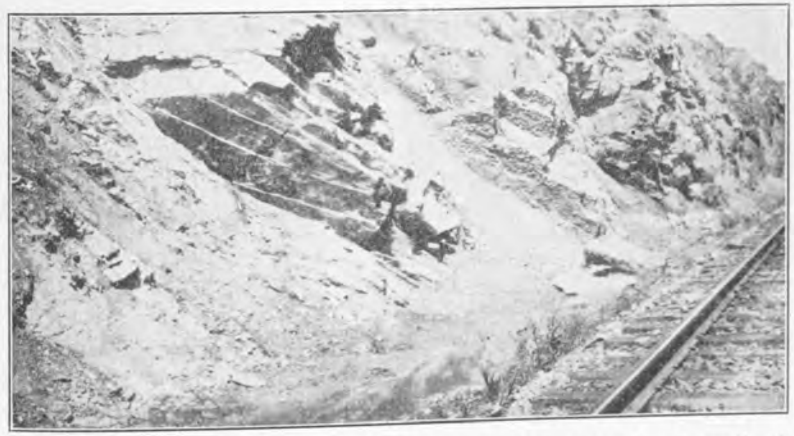


Fig. 18.—Steeply dipping Kinkaid beds in the railroad cut north of Crofton.

are thin, three to six inches, while others are more massive, reaching a thickness of two and one-half to three feet.

The shales are as variable in character as the limestones. They vary from light gray in color through dark gray to black or almost black. Some are thinly laminated and others more massive. They are as variable in composition as in the lithological features, some being entirely argillaceous, some calcareous and others highly arenaceous, especially in the lower and upper parts of the formation. At the top of the Kinkaid as it occurs in the railroad cut north of Crofton the formation consists of a series of shale layers interbedded with thin sandstone strata. (See Fig. 19.) In the lower part of the formation the shales are more arenaceous; a thin sandstone member is present locally, usually lighter gray in its color than the Degonia sandstone. Just below the contact with the overlying Pennsylvanian formations masses of residual chert are present in some localities. None of this chert has been observed in place but its position is such as to

suggest that it may be the product of pre-Pennsylvanian weathering.

Thickness. The thickness of the Clore alone as exposed in the railroad cut north of Crofton is approximately 50 feet, and the overlying sandstone which is believed to represent the Degonia has an average thickness of about 20 feet. The thickness of the Kinkaid differs greatly from place to place because of the varying amount of the pre-Pennsylvanian erosion. In places the whole of the Kinkaid and even more was removed so that the Pennsylvanian rests locally upon different members of the Kinkaid itself and even upon the Degonia and Clore, where all of the superjacent strata had been removed. In extreme cases all three of these formations were eroded and the Pennsylvanian rests upon the Palestine sandstone. The maximum thickness of the Kinkaid limestone in the Dawson Springs quadrangle is 100 feet or more. In the cut north of Crofton, affording an excellent section just outside of the quadrangle, 78 feet 1 inch of strata referable to this formation are exposed.

Stratigraphic Relations. The stratigraphic relation of the Clore with the underlying Palestine has already been considered and it seems to be a conformable sequence. Likewise all evidence seems to indicate that the Clore, Degonia, and Kinkaid constitute an unbroken stratigraphic sequence.

Wherever the contact between the top of the Chester and the overlying Pennsylvanian formations has been observed in western Kentucky, a great unconformity is present. Following the deposition of the last of the Chester sediments there was a period of erosion which lasted long enough for the streams to cut channels into the upper Chester equal to the thickness of the three upper units of the series, giving rise to the irregular contact between them and the basal Pennsylvanian.

Paleontology. The Clore limestone is not as abundantly fossiliferous as some of the lower Chester limestones, although in places fossils do occur in considerable numbers. The most favorable localities for collecting are from the calcareous shales immediately above the limestone beds. The limestone layers themselves are fossiliferous but the specimens are so firmly imbedded in the rock that in most cases it is difficult to secure them in a condition suitable for identification.

The most characteristic feature of the Clore fauna as a whole is the presence of small species of the bryozoan genus, *Batostomella,* in great numbers in some beds. Although these forms are met with in other Chester limestones, the Clore seems

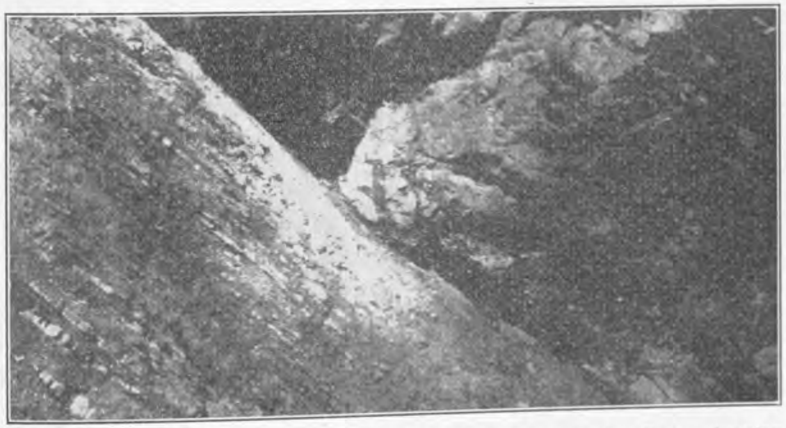


Fig. 19.—Contact between the Kinkaid (left) and the Pennsylvanian in the railroad cut north of Crofton.

to be the horizon where they occur most abundantly, especially *Batostomella nitidula.* Besides these bryozoa the other fossils most commonly present in the formation are the usual types of Chester bryozoa and brachiopods. One fairly representative collection was obtained from the beds exposed in the cut along the Louisville and Nashville railroad about a mile north of Crofton, just east of the Dawson Springs quadrangle, and the following species have been recognized:

Clore Fauna From North of Crofton

Pentremites sp.
Fistulipora excelens Ulrich
Meekopora sp.
Tabulipora tuberculata (Prout)
Anisotrypa sp.
Batostomella irregularis McFarlan (Mss.)
Batostomella nitidula Ulrich
Streblotrypa nickelsi Ulrich
Fenestella serratula Ulrich
Fenestella elevatipora Ulrich
Archimedes terebriformis Ulrich

Archimedes swallovanus Hall
Polypora spinulifera Ulrich
Polypora corticosa Ulrich
Septopora robusta var. intermedia Ulrich
Rhombopora tabulata Ulrich
Rhombopora minor Ulrich
Orthotetes kaskaskiensis (McChesney)
Productus ovatus Hall
Diaphragmus elegans (N. & P.)
Spiriferina transversa (McChesney)
Spiriferina spinosa (N. & P.)
Spirifer increbescens Hall
Spirifer sp.
Cliothyridina sublamellosa (Hall)
Composita subquadrata (Hall)
Spirorbis sp.

No fossils of any kind have been collected in the Degonia sandstone in the Dawson Springs quadrangle although it is not at all improbable that a more careful search might reveal more or less fragmentary plant remains such as occur in some of the other Chester sandstones of the area.

The Kinkaid formation is highly fossiliferous locally, but elsewhere much less so. The best preserved specimens may be obtained from the calcareous shale members in the upper part of the formation. Many of the limestone beds are fossiliferous but the shells are so firmly imbedded in the hard limestone that they can rarely be collected in good condition. Most of those which occur in the formation are long range forms all of which have been identified from beds lower in the Chester section, and the fauna as a whole is similar to those of some of the lower limestone formations of the series.

The most notable difference between the fauna of the Kinkaid and those from lower in the Chester is the relatively few Penetremites, crinoids, and bryozoans of the Fenestellid type. The examples of the brachiopod genus, *Composita* which change gradually from the type of *Composita trinuclea* in the lower and middle Chester to *Composita subquadrata* in the upper Chester limestones, exhibit a tendency in the Kinkaid to revert to more of a *Composita trinuclea* form although many typical examples of *Composita subquadrata* do exist. An interesting specimen of an undescribed species of the bryozoan genus, *Lioclema* was

found in one of the Kinkaid collections and a similar form has been recognized from the Kinkaid elsewhere and it may prove to be of diagnostic value.

The following lists represent the two most complete Kinkaid collections which have been secured. One of these was obtained from the exposure of the upper beds of the formation in the railroad cut north of Crofton, just outside the quadrangle, and the other from along the line of the Illinois Central railroad in the western part of the quadrangle about one-quarter of a mile east of Ruth.

Kinkaid Fossils From North of Crofton

Tabulipora tuberculata (Prout)
Batostomella sp.
Rhombopora minor Ulrich
Lioclema n. sp.
Fenestella serratula Ulrich
Polypora sp.
Diaphragmus fasciculatus (McChesney)
Spirifer increbescens Hall
Eumetria vera (Hall)
Cliothyridina sublamellosa (Hall)
Composita subquadrata (Hall)
Composita cf. trinuclea (Hall)

Kinkaid Fauna From East of Ruth

Triplophyllum spinulosum (M.-E. & H.)
Tabulipora rudis (Ulrich)
Tabulipora tuberculata (Prout)
Rhombopora sp.
Fenestella sp.
Polypora sp.
Orthotetes kaskaskiensis (McChesney)
Diaphragmus fasciculatus (McChesney)
Spirifer increbescens Hall
Eumetria vera (Hall)
Cliothyridina sublamellosa (Hall)
Composita subquadrata (Hall)

Correlation. The correlation of these three uppermost Chester formations, under consideration, throughout western Kentucky and southern Illinois is based primarily upon their stratigraphic position between the Palestine sandstone and the

basal Pennsylvanian formations, and wherever they have been studied throughout this region they display similar lithologic and paleontological characters. No fossils are recognized in either the Clore or Kinkaid limestones which, alone, constitute a certain basis of correlation. In the Clore the presence in large numbers of the bryozoan, *Batostomella nitidula*, is characteristic in many localities and although the genus and the species does occur in several other Chester horizons, it is not known elsewhere to be so prolific.

Pennsylvanian Formations

The Pennsylvanian formations of the Dawson Springs quadrangle have been studied in detail, only in so far as has been necessary to establish the Mississippian-Pennsylvanian contact and the relation of the basal Pennsylvanian to the underlying Chester formations. A more detailed report of the Pennsylvanian in this quadrangle has been published by A. F. Crider.[38]

Name. The Pennsylvanian system, commonly called the "Coal Measures" by the earlier geologists, was named by Williams from the state of Pennsylvania where many coal beds are typically developed.

Distribution. In the Dawson Springs quadrangle the Pennsylvanian formations cover approximately two thirds of the surface area, outcropping chiefly north and east of faults 4 and 20 on the fault map (Plate V). In a few localities south of these faults they outcrop in some of the fault blocks where they cap some of the highest hills. This situation suggests that the Pennsylvanian had a much wider distribution in former times. Only two outcrops of the uppermost Chester limestone exist north of the fault lines constituting the southern boundary of the continuous Pennsylvanian outcrop.

Lithologic Characters. The Pennsylvanian in the Dawson Springs quadrangle includes conglomerates, sandstones, shales, and thin coal and limestone beds, the coal and limestone being subordinate to the other types of sediments. In many localities the basal part of the formation is a massive sandstone conglomerate, thickly studded with white quartz pebbles. This conglomerate is not everywhere present at the base of the formation,

[38]A. F. Crider, Geology and Mineral Resources of the Dawson Springs Quadrangle, Kentucky Geological Survey, Series IV, Vol. II, part 1, 1911 pp. 7-68.

being replaced locally by finer sandstones. Higher in the series there is a great thickness of sandstones and shales with thin seams of coal and limestone.

The sandstones as a rule, are coarser textured than those of the Chester Series and the shales are generally more arenaceous

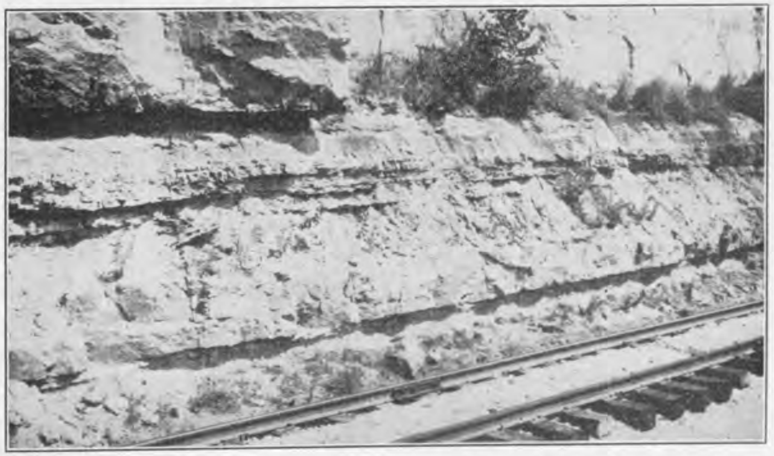


Fig. 20.—Kinkaid-Pennsylvanian contact along the Illinois Central railroad east of Ruth. Top of Kinkaid marked by line of vegetation.

and less thinly laminated. The limestone layer which occurs most persistently throughout the area is situated about 600 feet above the base of the formation. In most places it is about three feet thick although it attains a maximum of 20 feet locally. According to Crider there are four workable coal seams.

Thickness. Crider's estimate for the total thickness of the Pennsylvanian of this quadrangle is 800 feet, more or less.

Stratigraphic Relations. Throughout the Ohio valley, the Pennsylvanian is in unconformable contact with the underlying Chester Series. This unconformity is of far greater magnitude than any occurring within the Chester Series and must represent a long period of dry land conditions preceding Pennsylvanian time.

Paleontology. In addition to the usual plant fossils common to the Pennsylvanian in many localities, the limestone layers included in the section are abundantly fossiliferous in some outcrops. The fossils present consist of several species of

brachiopods, chiefly of the genera *Productus* and *Composita*, crinoids and bryozoa.

IGNEOUS ROCKS

No igneous dikes have been detected in the Dawson Springs quadrangle although such do occur in considerable numbers farther west, both in Kentucky and Illinois, the easternmost one known being in the Princeton quadrangle, north of Princeton.[39] The known dikes are narrow and much weathered and consequently hidden by surficial material. Many others doubtless exist which may never be discovered, and some such may be present in the Dawson Springs quadrangle.

ALLUVIUM

The only formation younger than the Pennsylvanian in the quadrangle is the alluvium, deposits of which are present along a number of the stream courses, especially Tradewater River and its larger tributaries from the south, in those parts of the valleys where the streams are flowing across areas underlain by the softer, less resistant shale and limestone of the older formations. Such deposits cover the valley floors to depths of 12 to 15 feet. It is not unlikely that much of this material has been carried down from the upland areas to the stream valleys since occupation of the region by white men by reason of the cutting away of the timber and cultivation of the hill lands. In recent years the removal of the surficial material of the uplands has progressed more rapidly because of the abandoning of many of the farms so that the deforested land, now left with no protection, has yielded readily to erosion of running water. The material of the flood plain deposits is of many sizes and is varied in composition. Much of it represents the final products of rock weathering, but the rapid erosion of later years also has carried down immense quantities of fragmental rock, the result of mechanical disintegration.

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[39] Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, pp. 97-98.

CHAPTER IV. STRUCTURAL GEOLOGY

INTRODUCTION

The structural geology in the Dawson Springs quadrangle is expressed in the cross sections (Plate IV) and the fault map (Plate V) which accompany this report. The determination of the true dip and strike of the beds is difficult in many of the outcrops in the Dawson Springs quadrangle. Slumping and cross bedding are common phenomena in the formations and the most careful observations in many places fail to distinguish true formational dips from the false dips. The most reliable method for determining the relations between the various formations is through observation of the elevations of formational contacts and these observations must be of the most careful sort in order to determine whether the different elevations of contacts are due to true dips, to variations caused by thickening or thinning of the beds or to the presence of unconformities between formations.

The aneroid barometer was commonly used to determine the elevations of the formational contacts. The use of this instrument involves a possible source of error, but for the most part it gives satisfactory results. Whenever practicable, contact elevations and intervals between formations were determined by hand leveling and in many sections the thickness of formations was measured directly. Notwithstanding all these precautions, some errors undoubtedly exist by reason of slumping and the accumulation of talus over the outcrops of the shale formations which has masked the actual contact.

In an area as complexly faulted as the Dawson Springs quadrangle the representation of structural conditions by means of structure contours drawn on some key bed is of less value than the representation by means of sections. Furthermore the formations that could be used as key horizons vary so greatly in thickness that the structure contour method would not be satisfactory.

STRUCTURAL RELATIONS

The Dawson Springs quadrangle constitutes but a small part of a much larger structural unit, extending both to the east and to the west, consequently interpretation of the structure in this particular quadrangle involves the consideration of a region reaching nearly to the Mississippi river, the whole of which must be considered as a unit. Complete detailed studies have not been carried to the east.

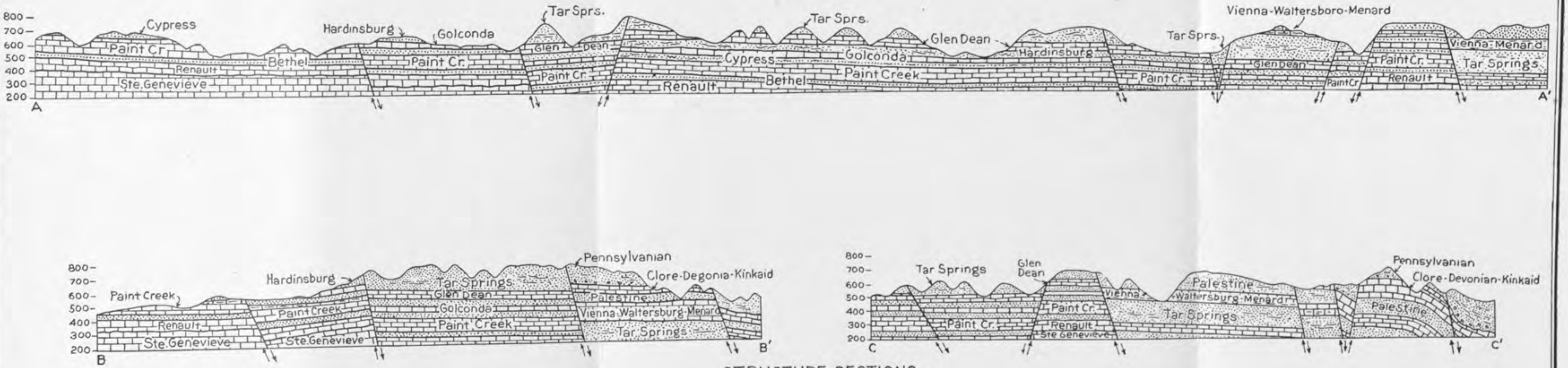
As in the more western part of Kentucky the regional dip of the rocks in the Dawson Springs quadrangle is toward the north and northeast. This dip has been modified in most localities by the complex faulting to which the region has been subjected. Originally the sedimentary strata of this part of Kentucky were nearly horizontal, but this general dip, augmented by the effects of faulting is sufficient to account for the passage beneath the surface of the entire thickness of about 900 feet of Chester sediments in a north-south distance of 14 miles from Hopkinsville to a point about one mile north of Crofton. These two places have about the same elevation above sea level, and are situated a little east of the Dawson Springs quadrangle. This dip would be equivalent to less than one degree, approximately 43 minutes, if the surface were exactly level.

Measuring along a northeast line from the southwest corner of the quadrangle to a point near the northeast corner of the southwest rectangle, the formations from the top of the Renault to the base of the Pennsylvanian pass beneath the surface in less than 7 miles, but here the point at the northeastern end of the line is almost 100 feet higher than the southwestern end.

PRINCIPAL STRUCTURAL FEATURES

The most important structural feature of the rocks of the quadrangle and of the larger area as well, is the presence of the faults occurring in great numbers and trending in almost all directions, within a complexly faulted belt. In this quadrangle as in the Princeton quadrangle to the west, the major faults have a general east and west direction but in the quadrangles which are situated to the northwest of the Princeton quadrangle as well as in southeastern Illinois, the conspicuous trend is northeast-southwest.

PLATE IV



STRUCTURE SECTIONS

DAWSON SPRINGS QUADRANGLE

Datum plane 200 feet above sea level

Horizontal Scale $\frac{1}{62500}$

Vertical Scale $\frac{1}{9600}$

Kentucky Geological Survey
Series VI, 1928
W. R. Jillson, Director

Geology by
A. H. Sutton
Field Work, 1926

Minor structural features of the Dawson Springs quadrangle are folding, jointing, and slumping.

Faulting

Criteria of Faulting. Only a few of the faults in the Dawson Springs quadrangle are exposed at the surface under conditions that permit the planes along which movement has taken place to be observed. If the unconsolidated materials of the surface were removed and the bed rock exposed in all places, it would be a simple matter to locate accurately all of the breaks in the rocks. As it is, because of the thick covering of surficial material which is present over much of the area, the location of the faults must be based upon other evidence than direct observation of the fracture planes.

The field criteria which can be used for the determination of the faults are of several kinds. The fundamental basis for working out the structure of any area of this kind is a thorough knowledge of the stratigraphic succession of formations present in the district, which in any area containing the Chester formations means a knowledge of the faunas of the various limestone formations.

If the fault dislocation is such as to bring two different kinds of sediments, such as limestone and sandstone together at the same elevation, the location of the fault may be determined as the line of division between the two sorts of rock. If the beds are completely exposed the position of the fault can be determined exactly, but where the beds are partially covered with surficial material, as is generally the case in this quadrangle, the existence of the fault can be established but it can be located only within certain limits, which vary, depending on the extent of exposed rock surfaces. If two limestone formations are brought into fault contact, the presence of the fault may be established, but not always definitely located, by means of paleontology. If the contiguous beds at the surface on the two sides of a fault are both sandstones similar in appearance and without fossils, then one must look to the underlying limestone formations in order to establish the identity or diversity of the sandstones.

In some localities where the formations are faulted but with a dislocation not great enough to bring beds of different forma-

tions adjacent to each other at the surface, the presence of the fault must be established on the basis of the elevations of formational contacts on opposite sides of the fault. Here, again, the exact position of the fault can not always be certainly determined. In some localities notable change in dip of the strata, either in direction or amount is a good criterion for determining the presence of a fault. In many places the beds on opposite sides of a fault strike in different directions or in the same direction with a pronounced difference in dip. Along some of the faults the beds close to the lines of dislocation have been so disturbed from their original position that they are now steeply inclined, becoming almost vertical locally, the strike of such steeply dipping layers indicating the direction of the fault. Some beds may show folding, due to the drag, resulting from the slipping of the beds along the fault surfaces.

In some places slickensides have been developed upon surfaces of fault movement, crushed and brecciated zones have been formed elsewhere and the existence of such phenomena is always evidence of faulting. The fractured zones along the faults constitute natural paths for the circulation of ground waters and consequently many springs issue along them, and in places they constitute good evidence of faults. However it can nowhere be taken for granted that a spring indicates the presence of a fault, for many issue elsewhere than along fault lines and the evidence in each case must be considered on its own merits. Some fractures have become loci for the deposition of mineral matter, especially crystalline calcite and the presence of calcite seams is important evidence in some places for the location of a fault.

Character of Faults. "A fault is a fracture in rocks along which there has been some displacement or dislocation of one side with respect to the other in a direction parallel with the fracture."[1] According to the usual classification of faults they are divided into two groups, normal or tension faults and reverse or compression faults often spoken of as thrust faults, depending on the direction of movement with respect to the inclination of the fault plane, but it must be kept in mind that these terms are descriptive only for the planes of the sections considered, and many faults may display "normal" characteristics in one place and "thrust" in another.

[1] C. K. Leith, Structural Geology, Henry Holt & Co., 1923, p. 65.

When a fault plane or surface is inclined from the vertical the rocks on one side of the fracture overhang those of the other. The overhanging side is called the "hanging wall" and the other the "foot wall." A normal fault is one in which the hanging wall has moved downward with respect to the foot wall, and a thrust fault, one in which the reverse movement has taken place. The former type is the result of tensional stresses and the latter the result of compressional stresses. Essentially all of the faults of the Dawson Springs quadrangle are of the normal or tension type, the beds of the hanging wall having moved downward with respect to those on the other side of the fracture.

Description of Faults. The faults of the Dawson Springs quadrangle are largely concentrated into belts extending east and west across it. One belt, that in the southern part of the quadrangle, is largely confined to the area of outcrop of the Chester formations and the lower part of the Pennsylvanian formations. In his map of the distribution of the Pennsylvanian of this area Crider[2] shows another belt of dominantly east-west faulting in the northern portion of the quadrangle. Faulting of a type similar to that in the southern part of the quadrangle undoubtedly exists farther north and careful work in the Pennsylvanian area certainly would reveal many more faults than have heretofore been mapped, especially cross faults between the east and west fractures, and these faults are probably less continuous than they have been represented.

Within the southern belt of faulting the pattern is highly complex, the faults extending in almost every direction, but with a general east-west trend for the longer ones and for the belt as a whole. Between the longer east-west faults the beds have been fractured along cross faults, breaking up the area into numerous blocks of different sizes and shapes. The beds in the several blocks are tilted in different directions but without noticeable folding except locally close to the fault lines.

The amount and complexity of the faulting is shown by the fact that 50 distinct faults have been mapped in connection with the Chester formations which cover only about one-third

[2] A. F. Crider, Geology and Mineral Resources of the Dawson Springs Quadrangle, Kentucky Geological Survey, Series VI, Vol. II, Part I, 1914.

of the quadrangle. These faults are not uniformly distributed throughout the area but are more numerous in certain places which are separated by areas of less complex faulting. Three

Fig. 21.—Small fault in the upper Chester beds in the railroad cut north of Crofton.

of these "knots" of faults are present in the southern part of the quadrangle and are shown on the areal geology map (Plate I). One is situated near the northwestern corner of the southwest rectangle, a second is near the northwestern corner

of the southeast rectangle, and the third is in the south central portion of the same rectangle.

A detailed description of the individual faults would necessitate a great amount of repetition, as most of them are similar in character, consequently the description will be confined chiefly to the more general features, illustrations being drawn from the faults best suited for the purpose. Although most of the faults are of the normal type, a few small breaks exist along which there has been some compression movement. The greatest component of movement has been in a vertical direction, although it is probable that some horizontal movement also has taken place, but horizontal movements are less readily detected from a study of the surface exposures and there is no opportunity to make observations in mines. The fault planes are inclined at high angles, some, where exposed, being almost vertical.

Along most of the faults the downthrow side is on the north or east of the lines of fractures, although there are some exceptions where fault blocks have slipped downward between bordering segments, leaving older formations at higher elevations on all sides, or elsewhere certain blocks stand stratigraphically higher than the surrounding areas. The rocks have been broken in such a manner by the faulting in most places that the blocks between faults have taken on the form of wedge-shaped segments that have settled irregularly in the process of adjustment to changed conditions of tensional stress.

The amount of vertical displacement resulting from the faulting is variable with different faults, some of the most extensive ones, horizontally, having least displacement. The fault having the greatest extent within the triangle is No. 32, with an east-west length of about 11 miles, but its maximum vertical displacement is only 40 feet and throughout most of its length not more than 25 feet. On the other hand No. 19, one of the shorter faults in the western part of the quadrangle, has a vertical throw of about 380 feet These two examples represent the two extremes, the amount of displacement along the other faults falling between these limits.

The faults which extend for the greatest distances across the quadrangle in east-west direction are Nos. 8, 19, 20, 28, and

32, all with the downthrow side to the north, the amount of displacement varying among different faults and also at different places on the same fault. Fault No. 4 extends in a southeastern direction from the western border of the quadrangle near Ruth to a point in the south central rectangle where it terminates against fault No. 32. It is of importance because it forms the boundary between the Chester and Pennsylvanian formations for a considerable distance. Just as there is much variation in the amount and direction of movement along the major faults of the area which trend east and west, so also similar variation is exhibited among the minor cross-faults.

In the adjustment to the conditions of stress which produced the faulting, the segments of the earth which form the several blocks, settled unequally not only in a vertical direction but also during the settling many of the blocks were tilted, leaving the beds lying at different angles ranging from horizontal to vertical. The greatest departure of the strata from a horizontal position is associated with faults 4, 5, 10, 11, 20, 21, 25, and 26. In the small block bounded by faults 8, 9, 10, and 12 the beds are vertical, while along some others angles of dip as high as 60 to 75 degrees have been observed. In the southern part of the faulted belt the beds are but little disturbed, except locally, from a horizontal position.

Origin of the Faulted Structure. The ultimate cause of the fault structures exhibited in this quadrangle can not be considered in terms of this small area alone, but must take into account the entire region characterized by this particular type of faulting and the relations between the structural features in the different parts of the "structural region." The character of the faults in this whole region of western Kentucky and southern Illinois is such as to imply that the deformative forces responsible for the faulting were in the nature of tensional stresses. The wedge-shaped segments comprising the various fault blocks appear to represent an original arch or dome of the rock strata broken apart during adjustment to stretching or tensional stresses produced by uplift dominantly from below and not by lateral compression. With a decrease in the active force from below the various segments settled downward, wedged themselves together and became adjusted to a contracted

interior. If such an interpretation is correct, then it is necessary to postulate conditions which would result in the uplifting of the strata of the region with a consequent production of tensional stresses, this condition being followed by a decrease in the force from below, permitting the rocks which had broken into irregular blocks or segments in response to the strain to settle back unequally.

One possible explanation of this type of normal faulting is to consider it the result of an igneous intrusion uplifting the overlying strata and accompanied by expansion due to heat, this uplift being followed by a lateral spreading of the magma and its shrinkage due to cooling and solidification.[3]

The proof of a theory of this sort must be established by field evidence. It is known that basic igneous dikes do exist in considerable numbers within this structural region of western Kentucky and southern Illinois, although none have been observed within the limits of the Dawson Springs quadrangle. These dikes must represent the outermost extension, so far as it has not been removed by erosion, of material connected with a much larger, more or less deeply buried mass of igneous rock, the dikes being mere stringers of magma which have penetrated to higher levels than the main mass. The magnitude of the parent magma is a matter of conjecture, for no mines or deep wells have penetrated it. Experimental data indicate that the angle at which an intrusion approaches the surface is more important than the size of the intrusion in determining the extent of the area of surface deformation and consequently the main mass, if deep seated, may be many miles distant, but if near the surface it may be close at hand.[4] The important fluorspar deposits in western Kentucky and southern Illinois are believed to be genetically connected with such a deeply buried igneous mass as has been suggested, the magma in all probability being the original source of the flourine and probably also of the calcium which has entered into the formation of the mineral.[5]

[3]C. K. Leith, Structural Geology, Henry Holt and Company, 1923, p. 74.
[4]T. A. Link, Mechanics of Jgneous Intrusions (Unpublsihed Thesis, University of Chicago).
[5]L. W. Currier, Illinois State Geological Survey Bulletin No. 41, 1920, pp. 247-304.

The prevailing trend of the major faults in various parts of the whole faulted region gives some idea of the possible center for the supposed deep-seated igneous mass. In the Dawson Springs and Princeton quadrangles the direction of this trend is generally east and west. In Crittenden and Livingston Counties, Kentucky, and Hardin and Pope Counties, Illinois, their direction is mostly northeast and southwest, becoming more nearly north and south in the center of Johnson County farther west. In southeastern Missouri and southwestern Illinois a system of faults has been mapped whose direction is northwest and southeast, but it is not at all certain that these faults have any connection with those of western Kentucky and southeastern Illinois. The deep burial of the older rocks beneath the Cretaceous of much of western Kentucky and southern Illinois hides the indications of faults to the south, if any such structure exists. The convergence of these lines of deformation, so far as they are known, is somewhere in western Kentucky, perhaps near Paducah, or in the southern tip of Illinois, and such a point may be near the center of the supposed igneous mass.

A deep seated intrusion centering somewhere in western Kentucky or southern Illinois may have produced the phenomena of arching, stretching, and breaking so pronounced in the strata of this part of the Mississippi and Ohio Valleys, greatest near the center and dying out with increasing distance from it. This suggestion is presented only as a possible explanation of the phenomena and a complete solution of the problem can be reached only when the structural conditions of a much larger region surrounding this area have been worked out in detail. It is possible that the deformation in this region may be associated with, and may be incidental to diastrophic changes in a much larger area.

Time of Faulting. Although fault movements evidently have taken place in this region during historic time, as evidenced by the New Madrid earthquakes of 1811 and 1812 and the slight shocks which make themselves felt annually, the main deformation occurred far back in geologic time. The youngest rocks which are definitely known to be involved in the faulting are of Pennsylvanian age. In the southwestern part of Kentucky and adjoining parts of adjacent states a considerable thickness of

Cretaceous strata exists which consists of unconsolidated clays, sands, and marls. If these sediments were affected by the faulting, the lines of fracture have not been detected, and being unconsolidated these materials would soon lose the surface effects of faulting. So far as can be detected, the faults in the hard rocks pass beneath the Cretaceous sediments, and if this situation is confirmed they must antedate the Cretaceous. The major part of the faulting probably occurred at about the close of the Paleozoic Era, but minor movements may have occurred at intervals down to the present time.

Folding

Folding of the rocks in the Dawson Springs quadrange is only incidental to the faulting, the beds being dragged into the faults locally and caused to assume the appearance of folding. This phenomenon is more pronounced in the thicker shales of the Pennsylvanian formations than in the alternating limestone and sandstone formations of the Chester Series which, because of the presence of the harder, more competent limestone layers, yielded to strains by breaking more abruptly across the beds.

Jointing

Although jointing is a common phenomenon in the rocks of the quadrangle, especially in the Chester Series and the lower part of the Pennsylvanian formations, no examples have been observed where the jointing can be used to determine the direction of application of the forces which caused the deformation by faulting. The limestone beds, especially, exhibit a variety of joints resulting from local deformation and slumping, which have a pronounced effect on the weathering of the formations, although not related apparently to the general diastrophism of the area.

Slumping

Locally the jointing of the rocks has resulted in interesting cases of slumping of the more massive formations. Massive blocks, commonly of sandstone, have become separated from the main mass of rock by mechanical erosion, solution, or the weathering of the underying formations and have slid down on shale slopes or have been left standing detached from the parent

ledges. In many places such blocks maintain a nearly horizontal position, but are separated from the main mass of the formation by a distinct gap.

CHAPTER V. HISTORICAL GEOLOGY

INTRODUCTION

The geological history of any region is interpreted from the rocks and from its topography. Since the rocks in the Dawson Springs quadrangle are all of sedimentary origin and mostly marine, a consideration of the geologic history of the area is primarily concerned with the changes in the distribution of land and water suggested by the character of sedimentation during the various stages of the time period involved. In addition to these considerations there are the diastrophic and erosion changes which have occurred since the deposition of the youngest hard rock formation in the area.

Although the oldest exposed formation of the quadrangle is the Renault limestone, the geological history may be carried much farther back through the observation of formations exposed at the surface in adjacent areas, and through the consideration of data supplied by deep well drillings.

PALEOZOIC ERA

DEVONIAN PERIOD

The oldest rocks anywhere in this much-deformed part of western Kentucky are those which have been identified by Weller from the drillings of a deep well near Cedar Hill in the Princeton quadrangle.[1] The oldest formation penetrated by this well has been identified as of middle Devonian age. It is a marine limestone, indicating deposition in relatively clear seas considerably removed from areas of high land. This limestone is succeeded by the Chattanooga shale 242 feet in thickness, which is a dark brown to black carbonaceous formation. The conditions under which this mechanically formed sediment was accumulated were widely different from those under which the underlying limestone was laid down. The sea must have been more restricted, nearby land must have furnished the sediment, and conditions must have been favorable for the existence of

[1]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, pp. 5-9.

abundant plant life to supply the carbonaceous material, animal fossils being almost wanting.

Lower Mississippian Period

During much of the Mississippian period the lands bordering the seas which covered this part of Kentucky must have been relatively low, contributing material largely devoid of mud and sand, as is shown by the great thicknesses of limestone which were deposited. These conditions continued until after the deposition of much of the Ste. Genevieve limestone, when some changes occurred, shown by the introduction into the section of the Rosiclare sandstone member of the formation. During the Ste. Genevieve stage the seas covering the central interior of the United States had a wide extent, in some directions being as great or greater than during any other part of the Mississippian period.

Chester Epoch

With the opening of Chester time, the conditions controlling sedimentation in the Ohio and Mississippi valleys were notably different from those which obtained during the earlier part of the period. After the deposition of the Ste. Genevieve formation the waters were completely withdrawn from this part of the Mississippi Valley embayment and the newly formed rocks were subjected to a period of erosion which produced the greatest unconformity in the entire Mississippian period. During the Chester epoch a series of oscillations occurred, which resulted in the deposition of various types of sediment in contrast to the dominantly limestone formations of the earlier Mississippian. The land masses bordering the waters were relatively higher and the seas more restricted in depth and areal extent than formerly. The result of these different conditions was the transportation to the seas by the streams of much more clastic material than formerly, to form the shales and sandstones of the Chester Series. From time to time the waters became deeper and limestone beds were deposited, interbedded with the clastic sediments.

As the Chester formations consist of an alternation of limestone-shale and sandstone formations, we must infer conditions of relatively deeper water, somewhat removed from the land, alternating with stages of more shallow seas and nearer land, each invasion and retreat of the water represented in the deposits by a pair of formations consisting of a sandstone below, succeeded by a limestone-shale formation.

In some of these oscillations the water was completely withdrawn, a condition which is shown by the erosional unconformities which are present between some of the formations. At other times the transition from limestone to sandstone formation was gradual, showing that the withdrawal of the water was not complete but rather a partial retreat followed by a re-invasion and that the change from one type of sediment to the other occurred without a complete interruption. The changes in the relation of land and water may have been the result of the withdrawal of the ocean waters due to the deepening of some ocean basin or to the uplift of the bordering land masses.

At the close of five of the eight oscillations of the ocean in Chester time, the withdrawal of the waters from this part of the Chester embayment was complete and resulted in erosional unconformities. Each pair of formations marks a stage in the Chester Series, and if the Chester formations could be traced beneath the Pennsylvanian strata to the edge of the embayment in which they were deposited, unconformities undoubtedly would be found between each limestone and the succeeding sandstone formation. However, for this quadrangle, the Chester epoch has been divided into five recognizable stages on the basis of the complete withdrawal of the water as recorded by the unconformities, the oscillations in which the retreat of the seas was not complete being treated as sub-stages.

Renault Stage. The oldest Chester formation of the Mississippi Valley section is the Aux Vases sandstone, but this formation is not present in western Kentucky, so that the only formation of the initial Chester stage is the Renault limestone. The withdrawal of the waters at the close of the Renault was sufficient to expose the whole of western Kentucky as dry land, and the return of the sea was accompanied by the deposition of sand and consequently produced the abrupt change in character of sediment in passing from the Renault limestone to the Bethel sandstone.

Bethel-Paint Creek-Cypress-Golconda Stage. As the Chester embayment again became submerged, streams from the bordering land brought down an abundance of sand, from which the Bethel sandstone was formed. This deposition continued uninterruptedly during Bethel time and continued into Paint Creek time, gradually changing from sandstone, through shale, to the limestone of the lower Paint Creek, indicating gradually increasing depth of water, which must have been due to the gradual northward movement of the shoreline during this time. Throughout Paint Creek time, conditions of depth of water and character of sediment varied from time to time, resulting in the deposition of the interbedded shale and limestone layers of the formation.

It has already been shown that the field evidence does not warrant the assumption of an unconformity between the Paint Creek and overlying Cypress in this portion of Kentucky. The change from the shale of the upper Paint Creek to the sandstone of the Cypress took place with no distinct break in sedimentation and consequently without complete withdrawal of the waters from the area, but with changes in the distribution of land and water sufficient to cause the bringing in of coarser sediment, the result of a partial retreat of the sea or a slight uplift of the bordering land. Sedimentation continued uninterrupted, from the Cypress into the Golconda, the recurrence of limestone and shale conditions after the Cypress indicating periodic changes sufficient to permit the deposition of limestone with the shale of the Golconda.

Hardinsburg-Glen Dean Stage. After the Golconda deposition the waters were completely withdrawn from this portion of the Chester embayment and the rocks were exposed to the processes of weathering and erosion. This conclusion is based upon the existence of the unconformity between the Golconda and Hardinsburg. The invading Hardinsburg sea deposited sand, as was usual under such conditions. The transition from the sand of the Hardinsburg to the deeper water sediments of the Glen Dean occurred with no interruption and continued throughout the latter, with only intermittent changes in conditions sufficient to cause the laying down of limestone at certain times and places and shales elsewhere, these conditions being

associated with the northward progress of the advancing shore line.

Tar Springs-Vienna-Waltersburg-Menard Stage. That the waters again retreated from this area at the close of the Glen Dean substage is shown by the unconformity between the Glen Dean and Tar Springs. The existence of the Tar Springs sands above the unconformity is the result of the re-advancing sea and the distribution of materials being carried by streams draining the bordering lands. Minor oscillations of the sea occurred during the Tar Springs, Vienna, Waltersburg, and Menard stage which resulted in the deposition of the various shales, sandstones, and limestones of these formations, but the absence of any break in the stratigraphic continuity shows that the area was during none of this time completely emergent.

Palestine-Clore-Degonia-Kinkaid Stage. The Palestine is like the Tar Springs in representing an initial sedimentation above an unconformity, representing a completely emergent condition, but the absence of any unconformity in this area after Palestine time to the close of the Chester epoch shows that the oscillations indicated by the alternations of sandstones and limestones were not sufficient to raise the area above sea level, although further north emergent conditions must have existed at times.

Sources of the Chester Sediments

The determination of the sources from which the sediments comprising the various Chester formations were derived is a problem, the solution of which must be based on the changes in the character of the sediments and the thickening and thinning of the different formational units from place to place. This question can be answered satisfactorily only when complete data concerning the distribution of the several formations is available. The distribution of the surface exposures is fairly well known, but the extent of the Chester formations beneath the Pennsylvanian is a matter which can only be established by deep drilling, and only scattered information of this sort is now available. A careful analysis of the mineral content of the several sandstone formations may also supply important information. There is a possibility that materials may have been derived

from any of the lands bordering the embayment occupied by the Chester seas. Available data regarding the sandstone formations, which are the more important units in such an investigation, indicate that the material of the several sandstones may have been derived from different parts of the surrounding areas. Some of these formations thicken in one direction and others in another, but it is not unlikely that much of the material may have been transported by streams draining the country to the north, perhaps as far as Canada, and entering the head of the Chester embayment, perhaps in central Illinois.

Pennsylvanian Period

The retreat of the waters of the Chester embayment at the close of the Kinkaid stage was complete and eastern North America became dry land. The land thus exposed was subjected to a period of erosion which continued long enough for streams to dissect valleys from 100 to 200 feet below the level of the uplands. The Pennsylvanian period was essentially a time of periodic, progressive sinking of this area with respect to the bordering land masses. It began with a transgression of the water over the eroded surface of the upper Chester formations, accompanied by deposition, chiefly of sandstone and sandstone conglomerate, which probably were terrestrial. The rounded pebbles of white quartz which are included in the conglomerate layers must have been transported a long distance from a place where vein quartz existed in abundance.

The deposition of this part of the Pennsylvanian system was succeeded by the laying down of interbedded shales and sandstones, with a few thin layers of limestone and coal. The presence of cross-bedding and ripple marks suggests accumulation in relatively shallow water. The limestone layers show that during a part of the time, certainly, marine conditions existed. Much of the shale and sandstone also may be of marine origin, but some beds must have been deposited in bodies of water not freely connected with the ocean.

From time to time during the Pennsylvanian period the seas grew shallow and portions of the area became converted into swamps with abundant vegetation, the remains of which have resulted in the formation of thin coal seams. Periodically the

land became submerged, converting the swamps and lowlands into sites for the deposition of sediments which were laid down in deeper water. The alternation of these different sets of conditions accounts for the several coal seams which occur in the region.

Post-Pennsylvanian Faulting

Some time after the close of Pennsylvanian time, this portion of the Ohio Valley was subjected to deformation from which resulted the complex faulting which has been described. The exact time of the principal faulting is not known, but it must have been later than Pennsylvanian and earlier than Cretaceous. Not unlikely it was associated with the general diastrophic movements prevalent in North America at the close of the Paleozoic Era. Minor movements along some of the fractures have undoubtedly taken place intermittently from the first initiation of the movements to the present time.

MESOZOIC ERA

Triassic, Jurassic, and Comanchean Periods

Because no deposits of either of these three periods exist in this part of western Kentucky it is impossible to infer much concerning the history of the region during that time, but it may be assumed that the entire region was continuously dry land.

Cretaceous Period

In Cretaceous times an extension of the sea spread northward from the Gulf of Mexico, leaving deposits of sand and clay in western Kentucky and southern Illinois. None of these sediments are now known in the Dawson Springs quadrangle, but they may have existed here originally, their absence being due to later erosion.

CENOZOIC ERA

Tertiary

During Tertiary time the entire region now occupied by this portion of the Ohio Valley was base-levelled to an essentially peneplained surface. The exact date of the development of this peneplain is not known, but it is assigned to the early

Tertiary.[2] Closely related to this peneplanation, or perhaps contemporaneous with its last stages, thin deposits of sand and gravel accumulated locally, or possibly as a continuous layer over much of this region. These gravels are preserved today as remnants lying on the hilltops. None have been observed in the Dawson Springs quadrangle, but they are known upon some of the hills in the Princeton quadrangle[3] and in many localities in the Ohio and Mississippi valleys somewhat more removed from this district. These deposits, commonly referred to as the Lafayette Gravel, may have existed here formerly, now being entirely removed by erosion.

Quaternary

Pleistocene glaciation did not extend as far south as this part of the interior of the continent, and if any Pleistocene formations do exist here they are not glacial material in the proper sense of the word and would not be easily distinguished from the more recent surficial formations. The recent deposits of the quadrangle consist of the alluvium along the courses of the streams, notably the Tradewater river and its larger tributaries from the south.

PHYSIOGRAPHIC HISTORY

Presumably the Dawson Springs quadrangle has been emergent since the close of Pennsylvanian time, with the possible exception of a short period during the Cretaceous, the Tertiary gravels which may have existed here probably being a terrestrial formation. Just what physiographic changes occurred between the close of the Pennsylvanian and the time when the observable record begins, it is impossible to say. The first event of the physiographic history whose record is present is the development of the partial peneplain of the early Tertiary. This is recognized from the general accordant levels of the remaining uplands. The development of this peneplain is believed to have taken place some time during the early Tertiary, there being no evidence by means of which it can be dated within any closer limits. No doubt it should be correlated with the "Highland Rim" peneplain of adjacent areas.

[2]Isaih Bowman, Forest Physiography, John Wiley and Sons, 1911, p. 697.
[3]Stuart Weller, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923, pp. 93-95.

At some time since the development of this peneplained surface, the region was uplifted, and the last stage in the physiographic history has been the cutting downward of the present streams to develop a maximum relief of about 400 feet. Accompanying this degrading effect of the streams there has been deposition in the wider portions of the valleys where the streams are flowing across areas underlain by softer strata. The area now has the appearance of a low plateau, maturely dissected with silt-filled valleys.

SUMMARY

Location and Topography

The Dawson Springs quadrangle is located in the western part of Kentucky between parallels 37° 00′ and 37° 15′ north latitude and meridians 87° 30′ and 87° 45′ west longitude. The surface is in a state of mature topographic development, the nature of the topography depending largely on the character of the bedrock and to a lesser degree on the structure. The only industries of importance are farming, on a small scale, and coal mining.

Stratigraphy

The exposed hard rock formations are all of sedimentary origin and are Mississippian and Pennsylvanian in age, the oldest formation exposed being the Renault limestone of lower Chester age. All of the Chester formations that have been recognized in the Ohio Valley region, comprising approximately 900 feet of limestones, shales, and sandstones, variously interbedded, have been identified in the Dawson Springs quadrangle.

The sandstones are moderately fine grained quartz sandstone, yellow to brown in color, but locally showing considerable variations in color and texture. They range from thin layers a few inches thick to massive beds 10 to 15 feet thick. The limestone members are also variable, some beds being hard, dense and compact; others are more crystalline, and some are oolitic in texture. They vary in color from white through different shades of gray, buff, and yellow to brown or blue. Individual beds range from a fraction of an inch to as much as 7 feet in thickness. Many of the limestone beds are highly fossili-

ferous, others less so. The stratigraphy of the area can be interpreted chiefly through the limestone formations, whose identity is established on paleontological grounds. The shales are as variable in character as are the limestones. They vary from light gray to almost black in color, some are finely laminated and fissile and others more massive, and they show all gradations from purely argillaceous material to highly arenaceous or calcareous. Locally some are carbonaceous.

The Chester section in the quadrangle begins with a limestone at the base and includes 15 distinct formational units, alternating limestone-shale and sandstone formations. The complete section is as follows:

Upper Chester
- Kinkaid limestone
- Degonia sandstone
- Clore limestone
- Palestine sandstone
- Menard limestone
- Waltersburg sandstone
- Vienna limestone
- Tar Springs sandstone

Middle Chester
- Glen Dean limestone
- Hardinsburg standstone
- Golconda limestone
- Cypress sandstone

Lower Chester
- Paint Creek limestone
- Bethel sandstone
- Renault limestone

The Pennsylvanian system consists of a great variety of interbedded conglomerate, sandstone, shale, and thin limestone and coal layers.

Structure

The Dawson Springs quadrangle lies in the complexly faulted district of western Kentucky and southeastern Illinois, and is genetically connected with these areas. The faulting is all of the normal type, presumably the result of the intrusion of a deep-seated mass of igneous rock somewhere in this region after the deposition of the Pennsylvanian sediments. Folding

is local and incidental to the faulting. Jointing of the rocks is common, but can not be related to the larger structural features.

Geologic History

The geological history as interpreted from the rocks exposed begins with the deposition of the lowest Chester formation of the area. During this epoch the strand line of the Chester embayment oscillated back and forth over the Dawson Springs quadrangle and adjacent portions of the Mississippi and Ohio Valleys region, resulting in the deposition of the various Chester formations. During Pennsylvanian times the area, including the quadrangle, was subjected to a periodic, progressive sinking. At times the area was covered with water of considerable depth, in which the Pennsylvanian sediments were deposited until the bodies of water were converted into areas of swamp land, in which grew vegetation, the remains of which were buried under later sediments laid down after the next submergence and converted into coal.

Since the close of the Paleozoic Era the history has been simple. This whole surrounding region was reduced to a peneplaned condition in early Tertiary, since which time it has been elevated, and dissected by running water, until it is now a low, maturely dissected plateau, along the broader valleys of which there are considerable thickness of alluvial material.

BIBLIOGRAPHY

Bowman, Isaih, Forest Physiography, John Wiley & Sons, 1911.

Brokaw, A. D., Illinois State Geological Survey, Bulletin 35, 1916.

Butts, Charles, Mississippian Series in Western Kentucky, Kentucky Geological Survey, 1918.

Butts, Stephenson, Cooke, and Adams, Geology of Alabama, Geological Survey of Alabama, Special Report No. 14, 1926.

Crider, A. F., Report on the Geology and Mineral Resources of the Dawson Springs Quadrangle, Kentucky Geological Survey, Series IV, Vol. 11, Part I, 1914.

Fennemann, N. M., Physiographic Provinces of the United States, Annals of the Association of American Geographers, Vol. VI., 1917.

Jillson, W. R., Geological Map of Kentucky, Kentucky Geological Survey, Series VI, 1927.

Lamar, J. E., Geology and Mineral Resources of the Carbondale Quadrangle, Illinois State Geological Survey, Bulletin 48, 1925.

Leith, C. K., Structural Geology, Henry Holt & Co., 1923.

Link, T. A., Mechanics of Igneous Intrusions. (Unpublished thesis, University of Chicago.)

Owen, D. D., Second Report of the Kentucky Geological Survey, Vol. II, 1857.

Sayre, A. Nelson, Fauna of the Drum Limestone. (Unpublished thesis, University of Chicago.)

Ulrich, E. O., Professional Paper No. 36, United States Geological Survey, 1905.

Ulrich, E. O., Mississippian Series of Western Kentucky, Kentucky Geological Survey, 1918.

Weller, J. Marvin, Geology of Edmonson County, Kentucky Geological Survey, Series VI, Vol. 28, 1925 (In press).

Weller, Stuart, with the collaboration of Charles Butts, L. W. Currier, and R. D. Salisbury, Geology of Hardin County, Illinois State Geological Survey, Bulletin 41, 1920.

Weller, Stuart, Geology of the Princeton Quadrangle, Kentucky Geological Survey, Series VI, Vol. 10, 1923.

Weller, Stuart, The Chester Series of Illinois, The Journal of Geology, Vol. XXVIII, 1920.

Weller, Stuart, Geology of the Golconda Quadrangle, Kentucky Geological Survey, Series VI, Vol. 4, 1921.

Weller, Stuart, Transactions of the Illinois Academy of Science, Vol. VI, 1914.

Weller, Stuart, Illinois State Geological Survey, Monograph I, 1914.

Weller, Stuart, Geology of the Cave in Rock Quadrangle, Kentucky Geological Survey, Series VI, Vol. 26, 1927.

IV.

THE CRETACEOUS DEPOSITS OF TRIGG, LYON AND LIVINGSTON COUNTIES, KENTUCKY

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Illustrated with 10 Photographs, Maps and Diagrams

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THE CRETACEOUS DEPOSITS OF TRIGG, LYON, AND LIVINGSTON COUNTIES, KENTUCKY

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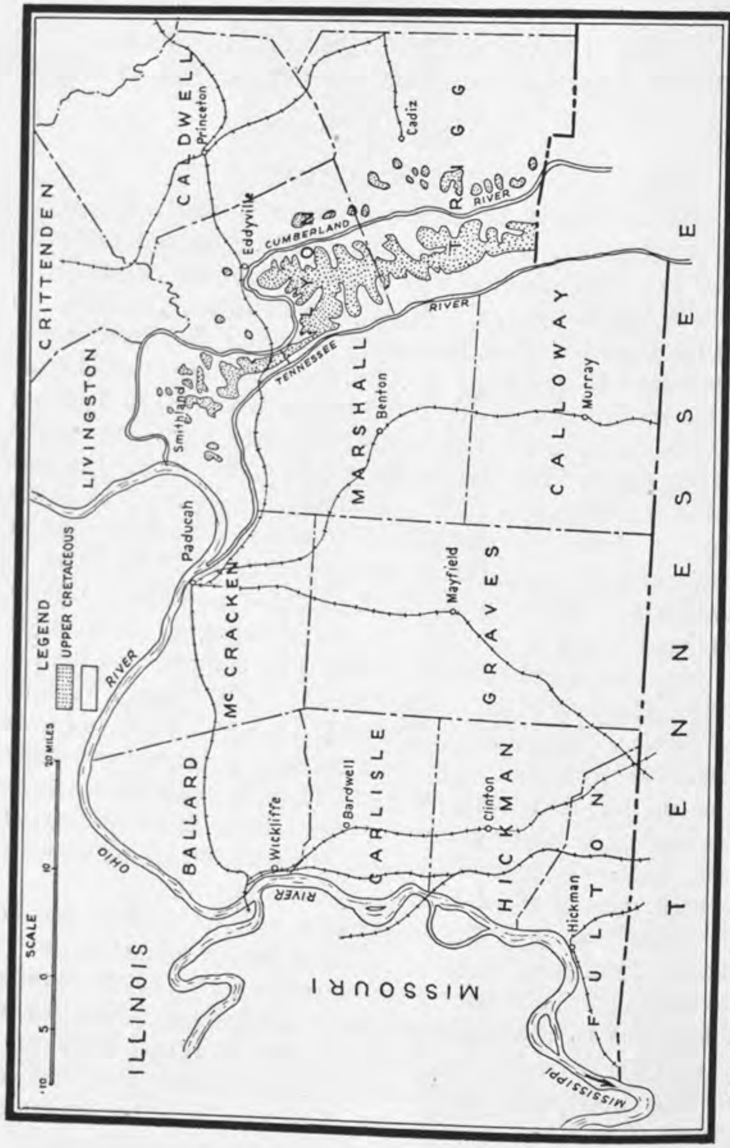
INTRODUCTION

The Cretaceous sediments of western Kentucky occur in Trigg, Lyon, Livingston, Calloway, Marshall and McCracken Counties. This discussion is restricted to the Cretaceous deposits of Trigg, Lyon, and Livingston Counties. In these counties the deposits occur principally between the Tennessee and Cumberland Rivers, but a very small portion has escaped erosion on the eastern side of the Cumberland River. The field work, which is the basis for this report, was done during the summer of 1926, and at that time no maps were available for the region west of the Tennessee River, commonly known as "The Jackson Purchase Area," hence this portion of the Cretaceous was neither mapped nor studied. For the work in Trigg, Lyon, and Livingston Counties, maps on the scale of one inch to the mile were used, which were made by a recent survey of these counties.

The section of country between the Tennessee and the Cumberland Rivers is often referred to as "the Coalings," or simply as "between the rivers," the former term being due to the fact that the charcoal used in the iron furnaces years ago was derived from the forests of this section. Though much of the forests was used some sixty or more years ago in this industry, one would not notice it at the present time, as the region is heavily forested, most of which is used for cross ties.

Trigg County is the largest of the three counties and borders on Tennessee; it has an area of 462.02 square miles. To the north of Trigg is Lyon County, with an area of 266.36 square miles. The northernmost county is Livingston, which borders on the Ohio River and has an area of 344.50 square miles.

The Cretaceous belt enters Trigg County from Stewart County, Tennessee, and at the state line it is approximately three miles wide. Towards the north its width is subject to considerable variation, and in some localities it attains as much as nine miles. The belt is approximately forty miles in length,



Sketch map, showing in general the extent of the Upper Cretaceous belt in Western Kentucky, East of Tennessee River.

and as it approaches the Ohio River it curves to the northwest and terminates in the western part of Livingston County, a short distance from the Ohio River. This belt between the Tennessee and Cumberland Rivers is continuous through Trigg and Lyon Counties, but north of Grand Rivers in Livingston County it is broken by erosion and occurs as isolated areas. East of the Cumberland River all the deposits are isolated and these areas diminish both in size and number towards the Ohio River. An outlying area as far east as Princeton, Caldwell County, has been located by Dr. L. C. Glenn, but as a general rule the majority of the Cretaceous deposits in the three counties on the east side of the Cumberland River lie near the river. It is quite likely that many of the areas east of the Cumberland River have been connected, or at least more so than at present, for they have been subject to erosion since late Cretaceous time. The enormous amount of erosion is evidenced by the deep ravines cut by the streams in the gravels and by the abundance of gravels carried by these smaller streams on to the floodplains of the larger rivers.

Physiography

A comprehensive study of the physiography of this section of Kentucky has never been made comparable to that of other portions of the State. Very little is known of the character of the country during Tertiary time pertaining to its drainage and other features. The territory between the rivers, and in fact all adjoining region to the three counties, is a part of what is termed the "Interior Low Plateaus." This plateau grades into the driftless area of the north and into the great embayment region towards the west and southwest; towards the east it fades into the great Cumberland Plateau. West of the Tennessee River the occurrence of Palezoic rocks is small, but these rocks are largely responsible for the relief in the Cretaceous belt and have been the important modifiers of the drainage both of the larger and the smaller streams. They have acted in the capacity of a support or a skeleton for the unconsolidated sediments of the Cretaceous age throughout these three counties and come to the surface in many of the gravel areas either by erosion or by faulting.

Drainage. The drainage of the Cretaceous area is more of the dendritic type and is taken care of by the Cumberland, Tennessee, and Ohio Rivers, and the numerous small tributaries which take their sources in the Cretaceous belt or to the area to the east of it. The Tennessee River forms the boundary on the west for three counties, and in general its course is parallel to that of the Cumberland. The Cumberland River cuts across Trigg and Lyon Counties and forms the eastern edge of Livingston County. The Tennessee, Cumberland, and Ohio Rivers form most of the boundary of Livingston County, leaving only a small portion along Crittenden County and another portion south of Grand Rivers on the Lyon County line, a distance of about one and five-eighths miles. The Cumberland and Tennessee Rivers are distant from each other in Trigg County from $6\frac{1}{2}$ to 9 miles, in Lyon County from 9 to 10 miles, but they approach each other at the northern edge of Lyon County by about $1\frac{5}{8}$ miles. At this narrow point the Tennessee River turns to the northwest for about five miles, then to the west and empties into the Ohio River on the eastern edge of Paducah. At this narrow point the Cumberland River turns due north to Dycusburg, from that point it turns sharply to the west for about 11 miles, and finally after meandering considerably it discharges into the Ohio River on the northern edge of Smithland, the county seat of Livingston County. The points of confluence of these two large rivers with the Ohio are approximately 12 miles apart. The Cumberland cuts across all three counties and meanders far more than the Tennessee. From all appearances the age relations of both the rivers are the same.

The watershed between the Tennessee and Cumberland Rivers is a little nearer the Tennessee from a fraction up to two miles, and the greatest difference exists in Trigg County. There are many small streams between these rivers. Most of them are very low or dry during much of the year, due to the water sinking into the porous gravels and sands. In most cases these smaller streams enter their master streams at right angles; some, however, flow parallel to their master streams for short distances along the level floodplains, and a few meander over the floodplain, as is the case with Crooked Creek in Trigg County, a tributary of the Cumberland River. Some of these smaller streams follow faults over some of their course.

The main tributaries on the eastern side of the Cumberland River take their sources well to the east of the Cretaceous deposits and are mainly responsible for cutting through the unconsolidated and once continuous gravel beds and leaving them as detached areas. As a general rule the streams enter the Cumberland River from the east, more at right angles than is the case on the west side of the Tennessee River. Such drainage habits are most likely due to the streams entering the Cumberland along the east-west faults, and the more or less straight faults determining their course, while west of the Tennessee the streams flow over the unconsolidated Cretaceous and Tertiary sediments and shape their own course. In the former case the cherty limestones are encountered, which permit of no meandering, while in the latter case the sands and clays west of the Tennessee River offer little resistance to lateral planation.

The larger tributaries of the Cumberland on its eastern side are Donaldson Creek and Little River in Trigg County, Eddy Creek in Lyon County, and Livingston Creek and Sandy Creek in Livingston County. Between the rivers the Cumberland receives Long, Ford, and Crooked Creeks in Trigg County, Long Creek in Lyon County, and Sugar and Hickory Creeks in Livingston County. The Tennessee River receives a few streams, which are very small and short, most of which are dry except for the wet seasons of the year. All these streams between the rivers take their sources in the Cretaceous gravels, and at times springs in the limestones feed them. Those streams which are fed by springs in the limestone are usually flowing all the year and free of the seasonal rainfall.

Along practically all the streams between the rivers there are reworked Cretaceous gravels, and such are mapped as Recent Alluvial deposits. This condition does not obtain so much to the eastern side of the Cumberland River. These gravels are clean, as their matrix material has been removed by the streams, and they furnish very fine gravel for concrete purposes.

Relief. The Cretaceous gravels occur on the tops and well down along the sides of the hills. The hills rise to elevations of as much as 100 to 250 feet above the level of the Tennessee

River. The Jefferson Davis Highway crosses the divide between the rivers in Trigg County west of Golden Pond, and the highest point on this road is about 275 feet above the low water mark of the Cumberland River. The Tennessee River is about 20 feet lower than the Cumberland, both estimated at low water mark by a number of barometer (aneroid) readings. In Lyon County the highest hills which have Cretaceous gravels are those of the "Coalings," and these have an elevation of 450 to 500 feet above sea level. In Livingston County the hills between the rivers rise to about 400 feet, while north of the Cumberland River the bench mark of the U. S. Geological Survey at Salem is 448.5 feet. The region east of the Cumberland River on the average is a little higher than that between the rivers. The hills are everywhere well dissected. They rise to about the same level and represent a dissected peneplain well into the age of maturity. This peneplain dates back to Tertiary time. The slopes of the watershed between the rivers possess a fairly low gradient directly below the summit, but become somewhat abrupt near the floodplain, because at these points the Mississippian rocks underlying the Cretaceous are exposed and their great resistance to erosion makes possible steep cliffs.

The floodplains of both the Tennessee and Cumberland Rivers vary in width up to two miles, the average being less than a mile. The floodplain of the Cumberland River is widest in Trigg County, though in some places in Lyon and Livingston Counties its width exceeds that in Trigg County. The great bend in the Cumberland River, which constitutes the northeastern boundary of Livingston County, has formed a fairly large floodplain on the concave side.

The streams which drain the regions east and west of the Cumberland River have cut through the gravels in many localities, especially near the floodplain. Such a condition exists in the village of Golden Pond, and in the case of Crooked Creek north of Golden Pond. In these instances the beds of the streams are in the Mississippian limestone. North of Pleasant Valley in Trigg County and at Ferguson Springs the limestones are exposed, due partly to erosion, but chiefly to faulting. The edge of the floodplain in Trigg County, and to a less extent in Lyon County, is easily recognized by the sharp and angular

limestone and chert fragments scattered over the surface, and this is better developed along the Cumberland than the Tennessee River.

The floodplain of the Ohio River nowhere reaches back to the Cretaceous sediments, but the effects of the cherty Mississippian limestones are well shown. This floodplain is very wide and especially near the junction of the Tennessee and Ohio Rivers.

The region between the rivers and to the east of the Cumberland River is well forested. The variety of timber is fairly large, but much of it is oak; it is sold chiefly as cross ties. The U. S. Government maintains a series of locks and dams on the Cumberland River. The locks in Kentucky are designated by letters. Lock —E— is located 3 miles up the river from Canton, Trigg County, and Lock —F— is at Eddyville, Lyon County, and is the last lock on the river. At present there are no bridges over any of the large rivers to accommodate automobile and other traffic, all of which depends upon ferries of private ownership. The Illinois Central System has bridges over the Tennessee and Cumberland Rivers in the vicinity of Grand Rivers.

The development of water power is rather limited due to the low gradient of the larger streams. Dams on these rivers would cause flooding of much of the floodplain area, which is about the only portion of the country suitable for farming. None of the smaller streams have a sufficient volume of water to develop power.

The uplands are not suited for farming, as the soil is not very fertile and the gravels too abundant. The floodplains are fertile and produce good yields of corn, which is the principal crop. Some of the floodplains are swampy and unsuited for farming except in seasons of low rainfall. The soil even on the high hills does not lack lime but when cleared of timber, it washes into gullies easily from the sand and gravel content. Often the Lafayette sands and gravels cover the tops of the hills towards the northern part of the Cretaceous belt, and gullies have cut the cleared fields until very little vegetation is able to grow. This type of soil even when looked after carefully and the gullies prevented does not hold moisture over short dry seasons, and it is not adapted to extensive and profitable farming.

Stratigraphy and Lithology

The Cretaceous belt of Kentucky is a portion and an extension of the Gulf belt, which begins in Georgia and extends across Alabama, Mississippi and Tennessee, and assumes a crescent shape. It extends over into southern Illinois, where it terminates at the Mississippi River floodplain. This belt reaches its maximum width along the Alabama-Mississippi line and narrows considerably through Tennessee and Kentucky. The only members of the Cretaceous represented in the area studied for this report are the Tuscaloosa and the Eutaw, though west of the Tennessee River, Cretaceous sediments of still younger age are known. In the southernmost portion of this lunate belt, Stephenson has recognized, mapped, and described the Tuscaloosa, Eutaw, Selma and the Ripley formations. The Eutaw is made up of two members, namely, the Tombigbee and the Coffee sands and the Ripley has an upper part termed the McNairy sand member. Wade in his studies of the Upper Cretaceous in western Tennessee recognized the Tuscaloosa, Eutaw, Selma, and Ripley formations and he shows that the latter contains the McNairy sand member and the two fossiliferous horizons, which he termed the Coon Creek and Owl Creek tongues.

Among the earlier geologists, who studied the Upper Cretaceous sediments along the Kentucky-Tennessee boundary was Safford. In his Geology of Tennessee[1] he makes no reference to any gravels east of the Tennessee or Cumberland Rivers in Stewart County, Tennessee, of Cretaceous age. Nor does his geologic map, in the text referred to above, show any Cretaceous deposits in this region. He divided the Cretaceous into the Coffee Sand, the Greensand, and the Ripley Sand without designation as to whether these members were of Upper or Lower Cretaceous age.

A few years prior to his Geology of Tennessee, Safford published an article[2] in which he stated that the gravels he found in the Cretaceous were quite water worn and were derived from the cherts of the Mississippian, but he regarded them as of post-Cretaceous age.

[1]Geology of Tennessee. Nashville, 1869. Pp. 410-421.
[2]Amer. Jour. Sci., Vol. 2, Ser. 2, 1864, pp. 360-372.

William B. Caldwell, in his report on the Limonite ores of Trigg, Lyon, and Caldwell counties, Kentucky[3] advanced no opinions regarding the age of the gravels in which he must have found some of the limonite.

Loughridge, of course, dealt with the region west of the Tennessee River in his Jackson Purchase report and made no mention of the occurrence of gravel of Cretaceous age on the east side of the Tennesse River. He stated that the Cretaceous deposits west of this river consist of two distinct types, namely, the sands and the micaceous clays; the former restricted chiefly to the southern and the latter to the northern portion of the belt.

Ulrich and Smith in their report long economic lines[4] make mention of certain alluvial deposits older than Quaternary age occurring between the rivers; these deposits are composed of chert gravels and are found on the hills, but the authors do not assign any definite age to them.

Glenn in his discussion of the underground water of western Kentucky[5] had studied only those Cretaceous deposits west of the Tennessee River of Eutaw and younger age. Much of his discussion of the Eutaw applies to the small area of the same age in Trigg County.

In 1914, L. W. Stephenson[6] states that the Tuscaloosa formation gradually thins out and disappears near the Tennessee-Kentucky line and that the Eutaw formation extends something like 80 or 90 miles into Tennessee. The geologic map accompanying this text shows no Cretaceous deposits between the rivers except a small area in Livingston County of McNairy sands of the Ripley formation along the east side of the Tennessee River.

In 1914, Bruce Wade[7] states that the Tuscaloosa gravels occur in Perry County, Tennessee, and that their age has been determined by Hugh D. Miser, who had traced the overlying red sands (Eutaw) into Hardin County where he found a local-

[3]Geol. Surv. Ky., Part 8, Vol. 5, Ser. 2, 1888, pp. 251-264.
[4]Lead, Zinc, and Fluorspar Deposits of Western Kentucky. U. S. Geological Survey, Prof. Paper 36, 1905, p. 70.
[5]U. S. Geol. Surv., Water Supply & Irrigation Paper 164, 1906, pp. 23-29.
[6]U. S. Geol. Surv., Prof. Paper 81, 1914, p. 14.
[7]Tenn. Geol. Surv., Resources of Tennessee, Vol. 4, 1914, p. 173.

ity showing Cretaceous fossils. This determination of the age of the gravels as Tuscaloosa in Perry County, near the middle of the state from the Kentucky line, was an important advance in Upper Cretaceous geology. Wade shows the extent of the Tuscaloosa gravels in Perry county in this report.

In 1915 L. M. Sellier mapped the Cretaceous gravels west of Golden Pond, Trigg County, along the Davis Highway. This marks the first recognition of Cretaceous sediments between the rivers in Kentucky, and the gravel belt appears on the Geological Map of Kentucky.

In 1917, Wade in discussing the "Gravels of the West Tennessee Valley"[8] mentions the occurrence of the Tuscaloosa gravels, cited by Sellier, and he visited the locality west of Canton in Trigg County. He suggested that an investigation of the plateau region between the Tennessee and the Cumberland rivers might show the extension of the gravels in isolated areas.

In 1919, E. W. Berry in his "Upper Cretaceous Floras" of the Eastern Gulf Region of Tennessee, Mississippi, Alabama and Georgia[9] shows on the geological map accompanying the text the extent of the Tuscaloosa and the Eutaw undifferentiated through Trigg and into the southern edge of Lyon County between the rivers; the Ripley is shown west of the Tennessee River, but no deposits are indicated east of the Cumberland River. No discussion is given the Kentucky deposits of Tuscaloosa age, though much of lithology of the formation in the other states applies to the belt between the rivers.

In 1920, Wade, in his report on "The Recent Studies of the Upper Cretaceous of Tennessee[10]" shows an isolated area of Tuscaloosa gravels and Eutaw sands in Stewart County, Tennessee, extending up to the Kentucky line. He discusses the character of the sediments of these two formations. This is one of the most important advances up to this time in the mapping and the systematic study of the northward extension of the Gulf Cretaceous belt.

W. R. Jillson, in 1920, called attention to the occurrence of Cretaceous sediments between the rivers.[11]

[8]Tenn. Geol. Surv., Resources of Tennessee, Vol. 7, 1917, pp. 62-63.
[9]U. S. Geol. Surv., Prof. Paper 112, 1919.
[10]Tenn. Geol. Surv., Bull. 23, 1920, pp. 52-58.
[11]Paper read before the Kentucky Academy of Science, May 1920. Abstracted in Ky. Acad. Sci., Trans., Vol. 1 (1914-23), 1924, pp. 81-83.

In 1921, High D. Miser's Mineral Resources of the Waynesboro Quadrangle, Tennessee[12] gives a short discussion to the Tuscaloosa and Eutaw members and to the iron ores, which in part are associated with the Tuscaloosa gravels. The determination of the age relations of these gravels, referred to above, has made possible the tracing and correlation of these deposits in Kentucky by Wade, and subsequently their extension across to the Ohio River.

In 1926, the Fauna of the Ripley formation on Coon Creek, Tennessee by Bruce Wade appeared[13] and the sedimentary aspect and to some extent the geologic history of Tuscaloosa and Eutaw time are considered.

The gravels between the rivers have been assigned various ages ranging from Cretaceous to comparatively recent times. On a geologic map of Trigg and Christian Counties by F. J. Fohs, published during the administration of Charles J. Norwood, State Geologist, most of the gravels in the southern portion of Trigg County are termed, "Tennessee River Gravel" of lower-most Quaternary age, and no deposits are shown north of Golden Pond along the higher hills. The absence of fossil floras and faunas has been the main handicap in the recognition of the age relationship of the gravels and sands.

Tuscaloosa Formation. The Tuscaloosa gravels are the most important as well as the most extensive group of exposed sediments between the rivers, and make up the entire Cretaceous sediments east of the Cumberland River. This term was first applied to the basal Upper Cretaceous deposits in the vicinity of Tuscaloosa, Alabama, by Smith and Johnson.[14] Later a note by Smith appeared[15] in which he expressed his opinion that the sediments are of Lower Cretaceous and in part at least the equivalent of the Potomac of McGee. He also pointed out that the sediments rested unconformably upon the coal measures, and near Havana, Alabama, were composed of micaceous sands, which were remarkable for their brilliant colors of red, pink, purple, and yellow. The ages of the beds were determined by the fossil floras.

[12]Tenn. Geol. Surv., Bull. 26, 1921, pp. 25, 42-116.
[13]U. S. Geol. Surv., Prof. Paper 137, 1926, pp. 4-6.
[14]Smith, E. A., and Johnson, L. C.—Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee and Alabama Rivers. U. S. Geol. Surv., Bull. 43, 1887, p. 95.
[15] The Tuscaloosa Formation. Science, Vol. 19, 1892, p. 274.

There is no paleontological evidence in northern Tennessee or Kentucky upon which to base the age, but the age relations have been determined where there is sufficient floral and faunal evidence and traced into the area concerned. Without question these gravels are basal Upper Cretaceous in Kentucky, and here they lie unconformably upon cherty limestones of Mississippian age.

Occurrence. The Tuscaloosa gravels are found on the sides of the hills in Trigg County and along the sides and summits of the hills in Lyon and Livingston counties, and east of the Cumberland River the gravels are found mostly on the hill tops. The deposits have been cut through by erosion and frequently their basal portion is exposed. The best gravel exposures to be found are (1) along the Jefferson Davis Highway west of Golden Pond from the recently worked gravel pit over the divide to a point about one mile east of the Tennessee River and (2) in the two pits at Gravel Switch, north of Grand Rivers, Livingston County. The gravel pits in Livingston County afford the thickest section, and because of their fresh exposures, the gravels are most accessible.

Stratigraphy. The Tuscaloosa beds in Trigg County are well exposed at Golden Pond. A few hundred yards east of the village the basal gravels occur, and 0.9 mile west of Post Office the gravel pit shows the general character of the bedded deposit. This pit was worked recently to supply gravel for the Davis Highway. From this pit to the west along the highway the gravels outcrop until near the top of the divide the Eutaw sands set in, the contact of the two not well exposed. Passing over the divide at a point not far from top of the hill the gravels set in again and continue to a point about one mile east of the Tennessee River. The underlying rocks of Mississippian age are exposed in the small creek which runs through Golden Pond. Something like 20 feet of gravel are exposed in the pit west of Golden Pond.

The Tuscaloosa gravels have been estimated to be about 170 feet thick along the Davis highway. At only one point does there appear any indication of bedding planes, and this instance is in the pit where there is a westward dip of 19 degrees. The strike is a little east of north. At some points north of this

highway in Trigg County the gravels appear to be thicker than 170 feet, but as a general rule the beds thin out towards the north.

In Lyon County between the rivers the gravel shows a thickness of 40 to 110 feet. The best section is found southwest

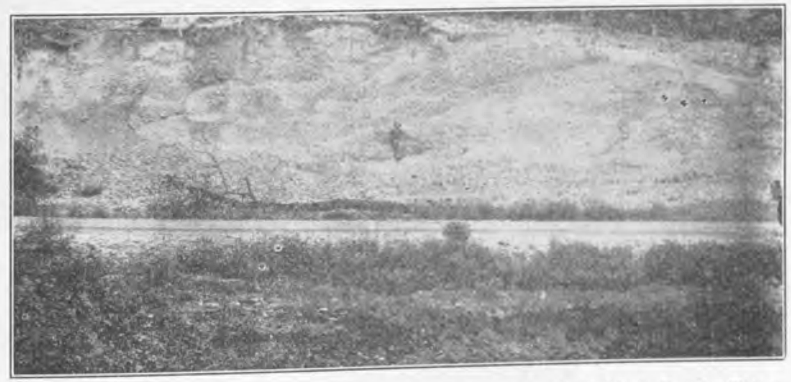


Fig. 1—View of the gravel pit, 0.9 mile west of Golden Pond, Trigg County, showing an exposure of Tuscaloosa gravels.

of Kuttawa in a cut on the Illinois Central System, and a second one between the rivers and about two and one-half miles south of the Lyon-Livingston County line. Through the "Coalings" there are no good exposures, and roads are about the only places where the gravels appear.

By far the best exposures are found in the two pits at Gravel Switch, now operated by the Memphis Stone and Gravel Company. In both the pits the gravel is about 110 feet thick. From this point on to the north and northwest in Livingston County the gravel bed becomes thinner and ceases to be continuous. Just east of Smithland near the high school building there are about ten feet of gravel, and this is the nearest occurrence to the Ohio River.

Lithology. The gravels consist for the most part of chert, and there are numerous limestone pebbles scattered through the beds. All are well rounded and some polished. They show evidence of being water-worn. Their diameters vary from a fraction of an inch up to three inches in the pit west of Golden Pond. A few pebbles in the pits at Gravel Switch measure as

Fig. 2—Typical Tuscaloosa gravel topography in the "Coalings," 4 miles west of Kuttawa, Lyon County.

Fig. 3—Near view of the Tuscaloosa gravels in the pit 0.9 mile west of Golden Pond, Trigg County. Width of photograph covers 40 inches.

much as fifteen inches. Probably the average is somewhere from one to two inches, and in such sizes rounding is most complete. Sometimes almost spherically shaped pebbles are found, but the majority are flattened and oval. Both the chert and

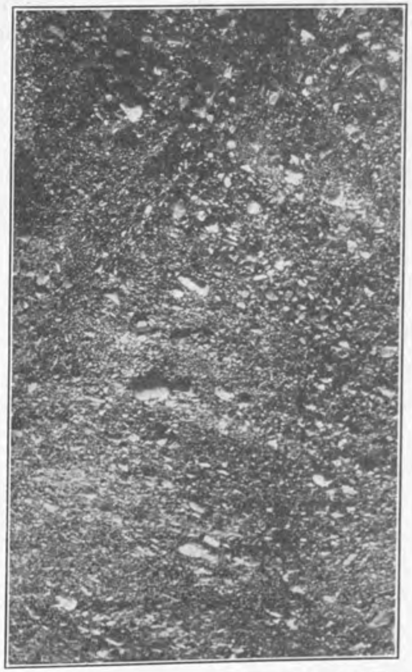


Fig. 4—Near view, showing cross bedding in the Tuscaloosa gravels in the Glynn Pit on the Memphis Stone and Gravel Company, Gravel Switch. Width of photograph covers 42 inches.

limestone pebbles contain bryozoa and brachiopods, and a few crinoid stems. As a general rule the pebbles are not highly sorted. The range in size is not very great in small thicknesses.

The matrix consists of finely divided calcareous and siliceous material, much of which is clay. Often hydrated iron oxides have cemented the gravels into highly indurated masses, but such layers are not very thick. In those exposures where rains and ground water have not removed the matrix, it varies from 8 to 15% of the gravel beds. The amount of clay present is about the proper ratio to the gravel to make it suitable for good metal.

Locally the Tuscaloosa contains clay lenses of small dimensions, which are termed "chalk" or "clay horsebacks" in the pits. These reach as much as five feet on the average and at times ten feet. The clay is very gritty and contains fragments of partially weathered chert, suggesting that the entire mass may be due to such weathering. The clay is not indurated to any degree, and shows no plant remains, as far as observation goes.

Masses of limonite are associated with the gravels in a number of the exposures and occur in the form of pockets of irregular shape and size. To some extent these limonite masses have been used in the past, though they are of scientific interest only for the present. They furnished the ore for the small iron furnaces operated prior to and shortly after the Civil War.

The lithologic character of the matrix and the pebbles is subject to considerable variation both vertically and horizontally. The pebbles show sufficient evidence that they have been derived from the cherts and limestone of the underlying Mississippian rocks, for the fossils in the pebbles are the same as those of the cherty limestones, which are found in place at nearby points. Many of these gravels have not been transported very far, and their rounding must be due to wave action, while others may have been rolled long distances.

The gravel beds as a whole present a light gray color when dry and a dark to medium gray when wet and free from iron oxides. The iron oxides are usually limited to a few layers and not disseminated through the beds. There is little or no organic matter present, it seems. When iron is present the gravels show a variety of colors, as brown, brownish red, yellow and a metallic black, depending upon the amount of iron and the degree of weathering. The indurated masses have a tendency to occur in horizontal position or dip at low angles. At times this habit has a tendency to suggest the bedding of the gravels, but such is only a problematical feature at best.

Eutaw Formation. The Eutaw formation is very poorly represented in Kentucky, and in the belt under consideration occurs only in Trigg County, between the rivers. The term Eutaw takes its origin from the town of that name in western

Alabama where Tuomey recognized certain beds as Cretaceous in age.[16]

The term was proposed later by E. W. Hilgard.[17]

The Eutaw maintains a fair uniformity throughout the belt over which it is found. The writer has had the opportunity of visiting a number of Eutaw localities in Alabama, Mississippi and Tennessee and the sands are essentially the same over these localities. All of the descriptions of the Eutaw by Stephenson, Berry, Wade and others agree within reasonable limits. There is nothing about the small thickness of Eutaw sand in Kentucky between the rivers in the lithologic sense that makes it different from that of Tennessee.

In Trigg County it is composed of red sands which have a textural range from coarse to medium and represents an extension of the Tennessee deposits. Farther south in Tennessee and Mississippi the sands contain colored clays and fragments of lignitized wood. So far no plant fossils have been found in Kentucky. The Eutaw was recognized and mapped in Stewart County, Tennessee, up to the Kentucky line by Wade.[18]

Stratigraphy. The Eutaw belt has a maximum width along the Kentucky-Tennessee line of a little more than one mile. From the state line the belt extends in a wedge shape to the north and terminates about the middle of the county between the rivers. No exposures of the sands have been found east of the Cumberland River.

These sands overlie the gravels unconformably in Tennessee, but this relationship was not observed, as no contact was seen. Along the Davis Highway, west of Golden Pond, the Eutaw sands are about forty feet thick. The sands in some places are overlain by a few feet of Lafayette sand and gravel. The thickness is computed on the basis that the bedding is horizontal or nearly so. In all probability the unconformable relations continue into Kentucky from Tennessee.

Lithology. The sands consist of quartz, with small and variable amounts of feldspars and micas and other rare min-

[16]First Biennial Repcrt on the Geology of Alabama. Tuscaloosa, 1850, pp. 118-120.

[17]Report on the Geology and Agriculture of Mississippi. Jackson, 1860, pp. 61-68.

[18]Recent Studies of the Upper Cretaceous of Tennessee. Tenn. Geol. Surv., Bull. 23, 1920, pp. 56-58.

erals. Sometimes small rounded pebbles occur, which may attain as much as one-fourth of an inch in diameter. These are composed of chert and quartz. The sand is weathered and colored by iron oxides. The color ranges from a dark red to reddish brown. The sand grains are from 20 to 100 mesh and the average is probably around 60. There is considerable clay in the sand, and this is colored by the iron oxides. Thin layers of the sand are sometimes indurated by iron oxides. Such induration is mostly restricted to the sands of coarser texture and comparatively free of clay.

Just south of Pleasant Valley a small lens of gritty clay outcrops in a ravine; this clay shows no plant remains. Some of it is very fine and well laminated, and it is not consolidated to any degree. Other occurrences were reported by several of the citizens, but none were located. The Eutaw, like the Tuscaloosa, unfossiliferous, can only be traced by its position in Kentucky and to a less extent by its lithology. It has extended farther to the north during Tertiary time probably and erosion has removed it.

A sample of the sand collected on the eastern side of the watershed to the west of Golden Pond, upon sieving, showed the following percentages:

Greater than 30 mesh	1.5%
Between 30 and 60 mesh	14.0
Between 60 and 100 mesh	68.5
Between 100 and 200 mesh	13.5
Less than 200 mesh	2.5
Total	100.0%

Section Along the Jefferson Davis Highway Between Golden Pond and the Tennessee River, Trigg County

Tertiary (Lafayette?) gravels exposed over a very narrow belt along the top of the divide. Heavily stained with iron oxides; unconsolidated and more uniform in size than the Cretaceous gravels .... 2 + ft.

—Unconformity—

Eutaw sands—medium to a deep red, coarse to a medium texture, micaceous and much of the mica weathered to chlorite; a few indurated layers due to iron oxides. Occurs on flanks of the divide .... 40 ft.

—?—Unconformity—?—

Tuscaloosa gravels—well exposed on both sides of the divide. Gravels well rounded, and varying up to three inches in diameter, composed of chert and to a less extent of limestone. Matrix composed of clayey matter with iron oxides, the latter giving rise to thick masses of consolidated gravels. The gravels are well exposed 0.9 mile west of Golden Pond and on the west side of the divide........ 170 ft.

—Unconformity—

Mississippian cherty limestone—exposed in the vicinity of Golden Pond, and much talus material seen both along the east and west sides of the divide.

Section in the Illinois Cntral Railway Cut 4 Miles Southwest of Kuttawa, Near the Overhead Bridge

Tertiary (Lafayette?) gravels—Well rounded and of light to medium red color, range in sizes small averaging less than an inch in diameter; matrix consists of a light red fine to coarse sand; beds dip about 18 degrees to the west. Several clay lenses and one with a thickness of about 5½ feet .... 10-25 ft.

—Unconformity—

Tuscaloosa gravels—well rounded, the gravels and matrix show a gray color, clayey matrix, frequent bodies of dove-colored sandy clay. Gravels average around one to two inches in diameter, and consist of chert and a few of limestone. Near the base of the gravels and resting upon the uneven surfaces of the Mississippian limestone are irregular masses of limonite as much as three feet thick, also a few pockets in the gravel near their base .... 20 ft.

—Unconformity—

Mississippian limestone a few of horizontal bed rock.

Section in the Glynn Gravel Pit of the Memphis Stone and Gravel Company, 1 Mile Northwest of Grand Rivers, Livingston County

Tertiary (Lafayette?) sand and gravel—gravels rounded, coated with iron oxides, average of less than an inch in diameter, matrix of coarse to medium textured red sand, unconsolidated	4-10 ft.
——————Unconformity——————	
Tuscaloosa gravels—light to medium gray color, some of the large boulders measure as much as 15 inches, the average being between one and two inches. Numerous masses of gray to dove sandy clay bodies. In places the gravels are strongly cross-bedded and these planes dip at about 40 degrees. Little evidence of bedding. Gravels not consolidated. Exposed	110 ft.

Structural Features

The structure of the Tuscaloosa and Eutaw formations appears to be relatively simple when compared to the highly faulted Mississippian rocks to the east of the Cretaceous belt. This is not a claim that the Cretaceous beds are not faulted by any means, but if they are faulted in their unconsolidated state it is almost impossible to locate such faults, especially in the absence of fossiliferous or persistent strata. Throughout the entire belt there is very little tendency for the gravel beds to show bedding planes, and what few are developed and exposed have low dips to the west. Cross-bedding is quite common in the gravels, especially with those beds composed of gravels of less than an inch in diameter. This habit is shown in the gravel pit west of Golden Pond and both of the pits at Gravel Switch. Bedding planes are not developed in the sands, but the weathering may have obliterated these.

Unconsolidation characterizes the sediments throughout Kentucky, except for the few beds which the iron oxides have cemented. This so-called "hardpan" is more widespread in the Tuscaloosa than in the Eutaw, and in the Cretaceous this habit is similar to that in the clays and sands of the Wilcox and Grenada west of the Tennessee River.

No folding, except of a monoclinal type, is seen, and that only in one locality. Faulting is common in the underlying Mississippian limestones, and this has been shown by Ulrich, Smith, Weller, and others. The mapping of the faults in the older rocks has been carried on in the region east of the Cretaceous sediments, and very few of these faults have been followed across the Cretaceous, or even up to their edge. The faults in the Paleozoic rocks have a northeast-southwest direction in Livingston and Crittenden Counties. Some of them have been traced up to the Cretaceous and to the floodplain of the Cumberland River. In Logan and Caldwell Counties the strike of these faults swings around more to an east-west trend. It appears most likely that all of the Paleozoic rocks are more or less faulted beneath the Cretaceous beds. The principal question that remains is the age of this faulting. If it took place and ceased prior to the accumulation of the Cretaceous sediments, the Cretaceous beds are not involved. But it is more likely that the faulting has been going on intermittently ever since the area was uplifted at the end of Cretaceous time. Elevation may be still taking place as erosion progresses and lightens the region.

There is evidence of a fault in Trigg County north of Pleasant Valley. This fault has brought the underlying limestones to the surface, or the base of the gravels has been cut through by erosion and the limestone eroded to some extent. Several springs in line in a northeastern direction suggest the presence of a fault. Between Energy and Ferguson Springs limestone is exposed on the east side of Crooked Creek, and gravels on the west side. No exposure has been located where the contact of the gravels and limestone is shown in this vicinity. Crooked Creek appears to follow the fault as far north as Ferguson Springs. In Lyon County five problematical faults have been mapped by others than the writer, and one of these—the Oakland fault, with an east-west direction—is shown as a definite fault in the "Coalings" for a distance of something like one and one-half miles. It is a very difficult matter to trace these faults, but when limestone outcrops in the gravel area, faulting is probably the better way of explaining the feature. Nowhere over the three counties was a faulted contact between

the Cretaceous and the older rocks observed. For the complex faulting in the Mississippian rocks to the north and east of the Cretaceaus belt the reader is referred to the recent publications of Stuart Weller.[19]

Fig. 5—An exposure of Mississippian Limestone, one-half mile south of Ferguson Springs, Trigg County, along a fault line.

Unconformable relations between the gravels and the underlying limestones are shown in a few places. The Eutaw formation is so weathered, as indicated above, that its contact with the underlying gravels of the Tuscaloosa is obscured. But the unconformity between the Lafayette and the Eutaw, or the Lafayette and the Tuscaloosa is easy to find.

Economic Geology

The natural resources of the Cretaceous consist exclusively of gravels. The Eutaw sands are so limited in quantity, and undesirable on account of their quality, that they possess no commercial value. They are high in iron oxides, and not even used for local purposes. The limonite is not of sufficient quantity to be classed as an ore, hence it is only of a scientific interest. Bordering the Cretaceous belt there is a considerable thickness of limestone, but that does not come within the scope of this paper.

[19]Geology of the Princeton Quadrangle, Kentucky. Ky. Geol. Surv., Vol. 10, 1923. Geology of the Golconda Quadrangle, Kentucky. Ky. Geol. Surv., Vol. 4, 1921. Geology of the Cave-in-Rock Quadrangle, Kentucky. Ky. Geo. Surv., Vol. 23, 1925. Structural Map of the Golconda and Cave-in-Rock Quadrangles, Kentucky. Ky. Geol. Surv., Map, 1925.

Tuscaloosa Gravels. The Tuscaloosa gravels occur in such large quantities in the three counties that their importance is of first magnitude, both locally and from the standpoint of state production of gravels. Deposits of a workable nature occur in all three counties. Gravels have not been used to any extent in Lyon County, and only locally in Trigg County. In the latter county they have been used for concrete and for road material on the Davis highway between the Cumberland and Tennessee Rivers. They have been quarried most extensively in Livingston County at Gravel Switch, to the northwest of Grand Rivers. These pits are among the largest gravel pits in Kentucky, and their annual output is large.

There are two pits at Gravel Switch. The larger of these pits is located east of the main highway and is commonly known as the Illinois Central Railway Pit. The other pit is west of the highway and opposite the larger one, and is known as the Glynn Pit, which adjoins the old Number 1 Pit, the first one opened some years ago by the Illinois Central Railway. The shipping point for both pits is Gravel Switch, which is reached by a spur track from the main lines of the above named railway.

These gravels are well suited for road material, railroad ballast and general construction purposes. Small amounts have been used locally. Along the small streams the gravels are found free from the matrix, and these are sometimes sorted and can readily be used for concrete and other purposes. The gravel industry has increased very considerably in the last few years, and the demand for building material calls for larger shipments each year.

The Kentucky Cretaceous gravel ranks well with gravels from the nearby states, and the state would do well to make more use of it in the construction of roads through western Kentucky. Using it in this section would eliminate long freight hauls on road material from outside the state which is no better, and sometimes inferior.

The first property sold for gravel pits in the vicinity of Grand Rivers was about 1886 when Jefferson Walker disposed of a small tract of land to the Chesapeake & Southwestern Railway. This company put in a steam shovel shortly after the purchase and shipped some gravel, but there is no record of the

Fig. 6.—View showing the face of the Glynn Pit, tipple, bins and power station. Memphis Stone & Gravel Company, Gravel Switch, Livingston County.

production. In 1898 C. C. Gressham sold 50 acres of gravel lands to the Chicago, St. Louis & New Orleans Railway Company; in March, 1914, Dixon & Sexton sold this same company 8.69 acres. In June, 1918, W. C. Bell sold this same company 50 acres, and a little later an additional 10 acres. In September, 1922, W. C. Bell sold the Memphis Stone and Gravel Company 22.76 acres; in June, 1924, 226 acres, and in September, 1926, 30 acres. The gravels taken from the small pits prior to 1913 were used for ballast, according to information received from the operators of the pits at the present time. Production was small and irregular, and little work was carried on during the winter season. None of the gravel was crushed, but was loaded at the pits and shipped.

The Glynn Pit. The first pit of any size was opened about 1912 and was known as Pit No. 1. It was operated by the Illinois Central Railway and used as ballast on their lines. This pit covered a small lease and was soon worked out. At that time the company opened up another pit, No. 2, east of the main highway and opposite No. 1, which is now known as the Illinois Pit. This second pit was operated for some time, and in 1921 was leased to the Memphis Stone and Gravel Company. Later this company bought land adjoining the old pit No. 1, which had been worked out, and opened up the present Glynn Pit through No. 1. So, at the present time, all the pits at Gravel Switch are operated by the Memphis Stone and Gravel Company, whose main offices are at Memphis, Tennessee, and shipping point is Gravel Switch, Kentucky.

The gravels taken from the pits prior to the lease to the Memphis Stone and Gravel Company were loaded into cars without being crushed, and shipped as ballast over the Illinois Central System. After this company began operations, machinery for crushing and handling large quantities of the stone was installed, and shipments are not only large but regular at the present time.

The overburden, which consists of a few feet of red, sandy soil and Tertiary sand and gravels, is removed by scrapers. Churn drills are used to put down holes for blasting, and the gravels are shot from the bank by dynamiting. The gravels, after their dislodgment, are loaded by steam shovels into small

cars and hauled by the narrow gauge yard locomotive over a tipple to the grading bins. These grading bins are constructed of wooden sides with a sloping floor made of parallel iron bars spaced about one inch apart. Gravels of an inch or less in diameter pass through these bars and are carried to the storage bins. Gravels too large to pass through these spaces slide down the inclined bottom and enter the crusher. From the crusher the material is carried by a bucket-belt line to the storage bins.

The machinery consists of three steam shovels — two of which are in use—one Williams crusher, one small yard locomotive, about thirty small cars, one large churn drill, and other accessories. The power used in the plant is developed by a 120-h.p. Fairbanks-Morse Diesel engine. Standard railway cars are run under the storage bins and loading is done by gravity.

The gravels, as mentioned under the lithology, are chiefly chert, with a little limestone. On a three-foot square surface of the face of the pit, ten pebbles of a limestone composition, measuring one-half an inch and over, and twenty-two of chert composition of varying sizes, were counted. When the material goes from the storage bins it tests on the average approximately 90% pebbles and broken fragments, and about 10% matrix. This matrix of an argillaceous composition makes an excellent binder when the material is used for ballast, and especially when applied to roads. In many ways these Cretaceous gravels are superior to the road material occurring at Camden, Tennessee, and the widely known and much-used Tishomingo gravels of Mississippi. It is superior to crushed limestone, as it has more binder, which compacts the pebbles quickly. Frequent clay masses, termed by the quarrymen as "Clay Horsebacks," give some trouble and have to be discarded. But the high grade of the gravel deposits, their uniform composition, the ratio of the matrix to the pebbles, ease of handling, convenience to transportation facilities, and freedom from groundwater troubles—these features make for the development of the deposits, so that operations are possible.

Much of the production is disposed of as ballast for the Illinois Central System. It is shipped long distances over their system. According to the official statement from the Illinois Central Engineer branch, the gravels are shipped as far west

over their system as Nebraska, as far north as Chicago, and much of it goes into the Mississippi delta region. Shipments for commercial purposes are made over much of western Kentucky and Tennessee and into the Yazoo Delta section of the northwestern Mississippi in the vicinity of Tunica and Clarksdale. Large amounts are used in and around Memphis for street, road, and concrete material, also in Paducah and through southern Illinois.

On the average gravel weighs about 3,000 pounds per cubic yard, but the gravels from the Glynn and the Illinois Central Railway pits average approximately 2,800 pounds. The production of gravel from 1913 to 1926 has been furnished by the Illinois Central System and the Memphis Stone and Gravel Company, which is appended to this report.

Illinois Central Railway Pit. This pit was opened by the Illinois Central Railway some time after 1916, when their supply of gravel was exhausted in Pit No. 1, and was known as Pit No. 2. After operating it for several years it was leased to the Memphis Stone and Gravel Company in December, 1921. It is much larger than the Glynn Pit and the gravels have been removed from an area of over twenty acres.

The thickness of the gravels is about 110 feet, and the overburden is of about the same character as that of the Glynn Pit. The gravel, after being shot from the bank, is loaded into railroad cars without crushing, and shipped as ballast for the Illinois Central System. Two steam shovels are used for loading in this pit. Operations are not constant, as production is controlled by the demand for the gravel on the railroad. The demand is greatest during the spring, summer, and fall.

All reports received from section superintendents of the railroads using the gravel claim that it is entirely satisfactory. The clay content is sufficient to bind the gravel, and makes a fine roadbed for the cross ties. The gravels do not give rise to so much plant growth, for much of the soluble matter needed for plants has been removed from the deposit by ground water circulating freely through it.

The gravel reserve in Livingston County north of Gravel Switch is large. The unfortunate feature about the gravels of Trigg and Lyon Counties is that most of the thick deposits are

Fig. 7—View showing the face of the Illinois Central Railway Pit, operated by the Memphis Stone & Gravel Company, Gravel Switch, Livingston County.

far from railroads and not convenient for trucking. In neither of these two counties will much gravel be used until bridges are built over the Cumberland and Tennessee Rivers, and the roads between the rivers improved. Bridges over these two large rivers at the points where they are crossed by the Davis Highway will open up the gravel resources for road improvement in western Kentucky. The State Highway Department will do well to consider these deposits in future road projects. The life of the gravel road, even without asphaltum, is as long as any rock road, and the clay matrix acting as a binder make it a more desirable road material than crushed stone. The chert pebbles wear very slowly and are superior to the terrace gravels found on the west side of the Tennessee River.

Production of the Gravel Pits at Gravel Switch, and that of Kentucky and the United States (Short Tons)

Year	Gravel Switch Pits	Kentucky	United States	Gravel Switch % of Ky.
1913	140,972	446,869	38,526,498	31.3%
1914	484,130	815,796	39,212,858	59.4
1915	387,118	448,897	37,972,548	86.2
1916	138,424	477,276	32,477,927	29.0
1917	112,547	*457,412	*35,573,819	24.6
1918	70,785	*427,239	*28,704,606	16.5
1919	288,473	†673,567	†25,890,829	42.8
1920	344,402	916,562	38,265,246	37.5
1921	239,792	‡575,304	‡41,550,054	41.7
1922	291,895	876,439	35,172,123	33.3
1923	503,983	1,320,303	72,566,882	38.1
1924	1,178,330	2,641,415	80,658,053	44.4
1925	747,620	1,495,637	84,819,251	49.9
1926	835,562	2,180,781	90,986,539	38.3
	5,765,433	11,752,797	682,377,233	40.9**

*Some gravel included under "Railroad ballast and gravel."
†Does not include some gravel under "Railroad ballast sand and gravel."
‡Does not include roofing gravels.
**Average.

Production at Gravel Switch for years 1913-21 inclusive furnished by courtesy of the Illinois Central System, Mr. A. E. Blaess, Chief Engineer.

Production at Gravel Switch for years 1922-26 inclusive furnished by courtesy of the Memphis Stone & Gravel Company, Mr. W. L. Smith, Pres.

The total Kentucky and U. S. Productions are taken from the U. S. Mineral Resources.

Production by Use reported by The Memphis Stone and Gravel Company, 1922-26.

Year	Number of Cars	Short Tons	Number of Cars	Short Tons	Total Production
1922	5,038	226,710	1,431	65,185	291,895
1923	8,977	403,965	1,993	100,018	503,983
1924	15,560	700,200	8,426	478,130	1,178,330
1925	12,994	584,729	3,152	162,891	747,620
1926	15,516	698,242	2,688	137,320	835,562
Total	58,085	2,613,846	17,690	943,544	3,557,390

Deposits of Limonite. Prior to the war between the states, and for some time thereafter, there were several small smelters in Trigg and Lyon Counties and in some of the adjoining counties. Trigg County was settled probably as early as 1778 and, according to the best available records, iron ore was smelted as early as 1841.[20]

According to Perrin, the principal furnaces in Trigg County, and the years in which they were established, are as follows: The Empire in 1841, and the Center shortly after, both furnaces near the Lyon County line; the Laura furnace in 1855, and three miles north of the Tennessee line; all three of these furnaces were between the rivers. East of the Cumberland River the Stacker Furnace was established in 1845 at Linton, on this river, and the Trigg furnace in 1871, five miles northwest of Cadiz. There were several furnaces in Lyon County, and the three largest were: The Fulton furnace, two and one-half miles west of the Cumberland River and about the same distance north of the Lyon-Trigg line; another furnace east of the Cumberland River, about one and one-half miles north of the Trigg line, and the third one at Eddyville. All of these early furnaces used charcoal, made from the wood of the forests close by, and the methods used in these furnaces, and by those towards the end of the period of their activity when coke was substituted for charcoal, are described by Caldwell.[21]

[20]Perrin, W. H.—History of Christian and Trigg Counties, Kentucky. Louisville, Kentucky, 1884, pp. 6-7.

[21]Caldwell, W. B.—Notes on the Coal and Iron Ores of Western Kentucky. Ky. Geol. Surv., Bull. 1, 1879 (?), pp. 46-59. Report on the Limonite Ores of Trigg, Lyon, and Caldwell Counties, known as the Cumberland River Ores. Ky. Geol. Surv., Rept. Progr., Pt. 8, Vol. 5, 2nd Ser., 1880, pp. 251-263.

The ores used in the furnaces were mined nearby, both between the rivers and east of the Cumberland River. Caldwell refers to the ore bodies in his discussions as beds or pockets, and in speaking of their origin makes use of the terms "pot

Fig. 8—Remains of the old smelter of Center Furnace, at Hematite Post Office, near the Trigg-Lyon line, Trigg County.

ore," "kidney ore" and "pipe ore" in clay or chert formation. All of the old furnaces were visited during the recent field work, and some of the old workings. None of the furnaces have operated since about 1880-85. The old pits are so fallen in and grown over by trees that they are hard to locate. Around all the furnace sites there are large quantities of blue and green slag, and in all but two cases this is all that remains to mark the location of these short-lived furnaces. A portion of Fulton

furnace is standing, and most of the brick work of Center furnace—the latter located near what is now known as Hematite Post Office.

The ore used by these furnaces was a limonite, which is found in pockets of variable size scattered through the gravels of Tuscaloosa age, and upon the Mississippian limestones. The latter occurrence was not noted in Trigg County, but it was reported by several people. Southwest of Kuttawa about four miles, in one of the deep cuts of the Illinois Central System, a small pocket of this ore is found. Here it occurs near the base of the Tuscaloosa gravels in a clay lens, which rests unconformably upon the indurated cherty Mississippian limestones. Everywhere the limonite was found during the field work, it is associated with clay, and in all probability the clay lenses played an important role in the formation of the nests or pockets from circulating ground waters bearing the iron oxides in solution.

However important these ores may have been three-quarters of a century ago, they are of no more than scientific interest at present. Most of the furnaces closed during the eighties of the last century and prior thereto, on account of the scarcity of the ore and the cost of removing the overburden. Also, the pockets were so irregular. The ores produced a high grade carbon steel. There is no hope for the revival of the iron interests in these counties at present for the above named reasons. Moreover, the competition brought about by the extensive rich Lake Superior and Birmingham ores will continue to crowd out such small and local occurrences for many years to come. A large furnace was built at Grand Rivers and operated a short while about the time of the World War, but this was soon closed down, as the ore had to be brought from outside the state. This expense, coupled with the great cost of coal and coke produced at a great distance, closed the plant.

In connection with the old furnaces an interesting feature was observed at the old site of the Fulton Furnace. It seems, from all reports, that this furnace was left after charging, and some years afterwards when it was dismantled large masses of partially smelted ore, mixed with slag, small fragments of charcoal and unusually large crystals of graphite, were broken up and left around the furnace. At this furnace site there are

small quantities of this material, which can be collected, showing these large flakes of graphite, some of which are as much as two centimeters across. Hand specimens can be had showing all the above mentioned materials. This habit may be very common in smelters, and especially in the old charcoal type, but this seemed interesting enough to call attention to, though it is a problem of metallurgy.

The pig iron was sold in Louisville, Cincinnati, St. Louis, and other nearby cities along the Ohio, Mississippi and Cumberland Rivers. At the time when the furnaces were operated, the demand for iron was good, as its reputation was widely known. There are numerous analyses of this ore, slag and coal in the older Kentucky reports, refernce to which will be found in the bibliography. It is not necessary to reprint these analyses in this report, since the iron deposits are of no commercial value any longer, and the analyses probably only approximate at best.

Geologic History

The geologic history of the region under discussion during the Cretaceous is difficult to interpret for several reasons, chiefly for the lack of fossil floras and faunas and the great amount of erosion. Ulrich and Smith determined the horizon on which the gravels rest as undifferentiated St. Louis, Spergen Hill, and Tullahoma limestones, and these are the youngest rocks of Paleozoic time present in this region. In all probability, land conditions obtained during Permian, Triassic, Jurassic, and Lower Cretaceous time. During this long interval there was considerable erosion, and there is no way of estimating this amount. The Mississippian beds are almost horizontal or dip at very low angles, and seemingly the uplifts have disturbed the strata very slightly as far as folding is concerned, but the matter of faulting is complex. There was no one period of uplift, but this has been going on gradually, keeping pace with erosion, thus keeping isostatic adjustments continuous from late Paleozoic time to the present.

Berry thinks the evidence in Alabama points to a delta origin for the Tuscaloosa gravels and associated sediments, and that sub-aerial conditions may have prevailed to some extent. The fossils of the Tuscaloosa in Alabama consist altogether of

land plants which are broken up, and point to a transportation by streams whose velocities were somewhat swift. Berry mentions that numerous tree fragments with pebbles intermingled with the roots are common in the Tuscaloosa. Also in Alabama there appears to have been ponds or bodies of water of a somewhat quiet nature in which clays accumulated, and leaves from the nearby trees became imbedded in the clays. Farther north in Tennessee the Tuscaloosa grades over into a gravel deposit with little or no sand and no pure clay lenses. In Kentucky only a few sandy clay lenses are found in the gravels, and these bear no fossils so far as observed.

The gravels throughout Kentucky are not sorted in many exposures observed, and even those beds in which any orientation occurs are of very small extent. The matrix is of an argillaceous composition, and always of a gray color, iron oxides playing no part in the coloration. It seems that if such gravels had been accumulated under purely continental environment with a warm, moist climate and an average vegetation, such as existed from indications of plants not far to the south, red ferric oxides would have formed and colored the sediments red. So, the water origin of the Kentucky gravels can hardly be doubted, from their degree of rounding, cross bedding, character of the matrix, position with respect to the parent rocks and included masses of white to light gray arenaceous clays. The few feet of overlying Eutaw sands are clearly of a marine origin in Trigg County, as these sands are an extension of the same sands, which to the south show evidences of accumulation under marine conditions. Whether the Eutaw sands extended farther to the north in Kentucky in late Cretaceous and early Tertiary time and later eroded is problematical; it does seem likely that they did have a more northern extent than at present.

The Tuscaloosa gravels through Kentucky and Tennessee and other regions to the south probably represent deposits from a sea transgressing the land, with a strand line moving towards the east and north, and laying down a basal conglomerate; at points where streams entered this sea the delta deposits were formed, this augmenting the thickness of the gravel deposits. The gravels were deposited farther to the east than they are found today and have been removed by erosion. Behind the

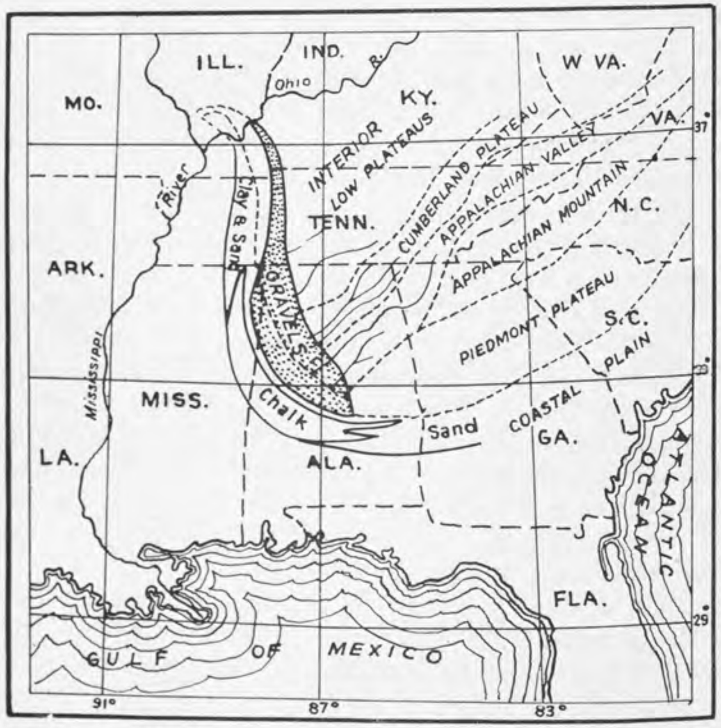
gravels, as the water became deeper and far enough away from the shore that the velocities of streams were slowed down, sands were accumulated. Then, upon the regression of this sea, as the strand line moved to the west and southwest, the gravels were built up further. As the rivers built out their deltas into the Upper Cretaceous sea, swamps with isolated bodies of water were formed, similar to those of the lower course of the Mississippi River, the Nile and other rivers, and into these bodies of still water, clays and other fine sediments were deposited. Probably much of the sand which filled this embayment area, both during Upper Cretaceous and Tertiary time, came from the gulf rather than directly from the land.

The belt of gravels has a lunate form, as shown by Berry, and his figure is repeated in this report, which shows the gravels extended across Kentucky to the Ohio River. A very small bed of the Tuscaloosa gravels occurs on the hill at Smithland near the present school building, about fifty feet higher than the level of the Ohio River, and this deposit was doubtless continuous over into southern Illinois. There are other very small areas of the gravels in this region, suggesting that the bed was continuous. Those beds of gravel which are thickest are most likely due to combined marine and river agencies. The streams had a southwest direction of flow and came from the uplands, which were being peneplained during Upper Cretaceous time.

There was no opportunity to examine in detail the Upper Cretaceous beds west of the Tennessee River in Kentucky, which have some floral or faunal remains. To postulate anything like a comprehensive history for the Upper Cretaceous in western Kentucky it would be necessary to study the portion west of the Tennessee River, which consists of greensands, sands, and small lenses of lignitic clay. At several points it is to be noted that the higher hills west of the Tennessee River are capped with Tertiary sands and gravel, and deeply buried Tuscaloosa gravels may occur in this region.

A study of the physiography of the Tennessee and Cumberland Rivers is needed in order to understand Cretaceous history. As to whether the long-contended case of piracy, which is claimed to have taken place with the Tennessee River south of Chattanooga is true or not, does not have so much bearing upon

the Kentucky region except that in case the Tennessee River was so increased in volume that it became a great agent of erosion. Probably much of the erosion in this part of Kentucky had already been done by middle Tertiary or even early Tertiary time.



Sketch map showing the probable physiographic provinces and drainage of Tuscaloosa time, extending from Georgia into Kentucky. (Modified after Berry, U. S. Geol. Surv., Prof. Paper 112, 1919, p. 27.)

The present area east of the gravel deposits covered by the Mississippian rocks is about 20 miles wide east of Livingston and Lyon Counties. From these rocks most of the Tuscaloosa gravels were derived. By river action alone it is difficult to understand how such thick deposits of gravels could have originated, collected from an area of this width; too, this Mississippian area borders on the Pennsylvanian rocks on its eastern side, and certainly much of the latter rocks have been removed

by erosion, thus making the space of Mississippian rocks over which the river flowed, smaller than it is today. Rounding of the pebbles could not have been so complete as it is, and wave action from the ocean must have been instrumental to a large extent in such rounding.

The nearest locality to Kentucky where Cretaceous plants have been collected by the writer is the Hooper Clay Pit, south of Hollow Rock Junction (Bruceton), Tennessee. These plants occur in the carbonaceous clay lenses of the McNairy sand member of the Ripley formation. If any fossiliferous clays occur in Kentucky, they are west of the Tennessee River, and so little is known of the detailed geology of this region at present that nothing can be said of the climate as indicated by the plants. The environment of Tuscaloosa time has been postulated as that of a uniform and abundant rainfall climate, ranging between semi-tropical and temperate conditions, with slight seasonal changes.[22]

During Eutaw time Berry thinks that the climate was moist and mild, and not so warm as Tuscaloosa. The absence of floras and faunas in Kentucky leaves only physical character of the sediments to draw conclusions from with regard to the Upper Cretaceous climate and general environment of the time. The withdrawal of the sea at the close of the Eutaw over what is now Trigg, Lyon, and Livingston Counties left the sediments in an unconsolidated condition and subject to sub-aerial erosion; this portion has remained land throughout Tertiary and Quaternary time, whatever the drainage may have been.

[22]Berry, E. W.—U. S. Geol. Surv., Prof. Paper 11, pp. 30, 35.

BIBLIOGRAPHY

Adams, George I.—The Course of the Tennessee River and the Physiography of the Southern Appalachian Region. Jour. Geol., Vol. 36, 1928, pp. 481-493.

Berry, E. W.—The Delta Character of the Tuscaloosa Formation. Johns Hopkins University Circ., n, s., 1917, pp. 18-24 (216-222).

The Upper Cretaceous Floras of the eastern Gulf Region in Tennessee, Mississippi, Alabama, and Georgia. U. S. Geol. Surv., Prof. Paper 112, 1919

The Age of the supposed Lower Cretaceous of Alabama. Geol. Soc. Wash., Jour., Vol. 13, 1923, pp. 433.435.

Caldwell, W. B.—Iron Ores and Coals—Advantages of western Kentucky for the Manufacture of Iron. Reprinted from the Courier-Journal, Louisville, Ky., March 9, 1878, 11 pp. Bull. 1, Ky. Geol. Surv., 1878, Pp. 46-59.

Report on the Limonite Ores of Trigg, Lyon, and Caldwell counties, known as the "Cumberland River Ores." Ky. Geol. Surv., Rept. Progr., Pt. 8, Vol. 5, Ser. 2, 1880, pp. 251-263.

Chamberlain, T. C. & Salisbury, R. D.—Geology (Text-book). Henry Holt & Company, New York, Vol. 3, 1907, p. 141.

Drake. N. F.—Economic Geology of the Waynesboro Quadrangle (Tenn.), Tenn. Geol. Surv., Res., Vol. 4, No. 3, 1914. Pp. 99-120.

Glenn, L. C.—Underground Waters of Tennessee and Kentucky west of the Tennessee River and of an Adjacent Area in Illinois. U. S. Geol. Surv., Water Supply & Irrig. Paper 164, 1906.

Hilgard, E. W.—Report on the Geology and Agriculture of Mississippi. Jackson, Miss., 1860, pp. 61-68.

Hoeing, J. B. & Fohs, F. J.—Map of Trigg and Christian counties (Ky.). Ky. Geol. Surv., (Date not given under the Norwood Directorship).

Jillson, W. R.—Geologic Map of Kentucky. Ky. Geol. Surv., Ser. VI, 1923, Scale: 1 inch to 1 mile.

The Occurrence of the Cretaceous sediments between the Cumberland and Tennessee Rivers in Western Kentucky. Ky. Acad. Sci., Trans., (7th Meeting) Vol. 1, 1924, pp 81-83.

Johnson, D. W.—The Tertiary History of the Tennessee River. Jour. Geol. Vol. 13, 1905, Pp. 194-231.

Loughridge, R. H.—Report on the Geological and Economic Features of the Jackson Purchase Region. Ky. Geol. Surv., 1888, pp. 32-36; 58-63.

Mayfield, S. M.—Geological Map of Livingston County (Ky.) Ky Geol Surv., Misc. Map Series VI, 1926.

Miser, H. D.—Mineral Resources of the Waynesboro Quadrangle, Tennessee. Tenn. Geol. Surv., Bull. 26, 1921.

Owen, D. D. & Others—Chemical Analyses of Ores, Rocks, Soils, Clays Marls, Iron Furnace Products, Mineral Waters, etc., of Kentucky. Ky. Geol. Surv., Vol. 4, 1861, 617, pp. 210-211; 254-264.

Perrin, W. H.—History of Christian and Trigg Counties, Kentucky, F. A. Battey Publ. Co., Chicago and Louisville, 1884, pp 6-7.

Peter, Robert—Chemical Report of the Minerals, Rocks and Soils (Ky.). Ky. Geol. Surv., Vol. 1, 1856. Pp. 341-344; 360.

Second Chemical Report on the Ores, Rocks, Soils, Coals, Mineral Waters, etc., of Kentucky. Ky. Geol. Surv., Vol. 1876, pp. 138-139; 173.

Peter, Robert and Talbutt, J. H.—Chemical Report of the Soils, Marls, Clays, Ores, Coals, Iron Furnace Products, Mineral Waters, etc., of Kentucky. Ky. Geol. Surv., pp. 4, Vol. 1, 1876, pp. 138-139; 173.

Richardson, C. H.—Glass Sands of Kentucky. Ky. Geol. Surv., Vol. 1, Ser. 6, 1920, pp. 105-106.

The Road Materials of Kentucky. Ky. Geol. Surv., Vol. 22, Ser., VI, 1924, p. 188.

Roberts, Joseph K.—The Tuscaloosa Formation of Kentucky. Am. Jour. Sci., Vol. 14, 1928, pp. 465-472.

Safford, J. M.—On the Cretaceous and Superior Formations of west Tennessee. Amer. Jour. Sci., Vol. 37, Ser. 2, 1864, pp. 360-372.

Geology of Tennessee. Nashville, Tennessee, 1869, pp. 410-421.

Shaler, N. S.—A General Account of the Commonwealth of Kentucky. Ky. Geol. Surv., Vol. 2, n. s. 1877, (For the Phila. Cent. Expo., 1876), pp. 69-72 (427-421).

Smith, E. A.—The Tuscaloosa Formation. Science, Vol. 19, 1892, p. 274.

Tuomey, M.—First Biennial Report on the Geology of Alabama. Tuscaloosa, Alabama, 1850, pp. 118-120.

Ulrich, E. O., & Smith, W. S. T.—The Lead, Zinc, and Fluorspar Deposits of Western Kentucky. U. S. Geol. Surv., Prof. Paper, 36, 1905, p. 70.

Wade, Bruce—The Geology of Perry County (Tenn.). Tenn. Geol. Surv., Resources, Vol. 4, 1914, pp. 151-181.

The Gravels of the west Tennessee Valley. Tenn. Geol. Surv., Resources, Vol. 7, 1917, pp. 55-59.

The Occurrence of the Tuscaloosa Formation as far north as Kentucky. The Johns Hopkins University Circular, n. s., 1917, No. 3, pp. 102-106 (300-304).

Recent Studies of the Upper Cretaceous of Tennessee. Tenn. Geol. Surv., Bull. 23, 1920, pp. 51-64.

The Fauna of the Ripley Formation on Coon Creek, Tennessee. U. S. Geol. Surv., Prof. Paper 137, 1926, pp. 4-6.

Weller, Stuart—Geology of the Golconda Quadrangle. Ky. Geol. Surv., Vol. 4, 1921. Geology of the Princeton Quadrangle. Ky. Geol. Surv., Vol. 10, 1923.

Geology of the Cave-in-Rock Quadrangle, Kentucky. Ky. Geol. Surv., Vol. 23, 1925.

Structural Geology of the Golconda and Cave-in-Rock Quadrangles. Ky. Geol. Surv., 1925.

Woodruff, J. G.—Geographical Map of Trigg County. Ky. Geol. Surv., Misc. Maps, Ser. VI, 1926. Scale: 1 inch to the mile.

Geographical Map of Lyon County. Ky. Geol. Surv., Misc. Maps, Ser. VI, 1926. Scale: 1 inch to the mile.

V.

THE GEOLOGY AND PHYSIOGRAPHY OF THE MAMMOTH CAVE NATIONAL PARK

By

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Illustrated with 39 Photographs, Maps, and Diagrams

Preface

Public opinion long ago recognized the Mammoth Cave as one of the principal features of geological interest not only in Kentucky but in the entire Ohio Valley. As the years have passed countless thousands from all parts of the world have found their way to and through this great cavernous region. Strange as it may seem, though individual effort has done much to popularize the Mammoth Cave and the many other adjacent caverns, official action in this direction until recently has been all but lacking.

With the movement now essentially completed to establish a National Park in this picturesque and delightful region, it has seemed expedient to prepare a popular treatment—a geological and physiographic guide book, so to speak—that might in a readable manner acquaint the traveler with the outstanding surface and subterranean geological features of this district.

In this little booklet Dr. Lobeck, one of the really able physiographers of the United States, has presented an exposition of this character which is outstanding in its illustrations, inked drawings, all from the author's pen, and typical photographs from his camera. In all the extensive literature descriptive of the Mammoth Cave area there is nothing like this—nothing so readable, so scientific, so fine.

July 18, 1928,
Old Capitol Bldg.,
Frankfort, Kentucky

W. R. Jillson
State Geologist

(*Reprint of Pamphlet XXI.*, 1928.)

Illustrations

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THE GEOLOGY AND PHYSIOGRAPHY OF MAMMOTH CAVE NATIONAL PARK

By A. K. Lobeck

INTRODUCTION

Most visitors to the Mammoth Cave National Park region will reach it either by the Dixie Highway or by the main line of the Louisville and Nashville Railroad. Those coming from the north will pass through Louisville; those from the south will go through Nashville. The cave region is about midway between these two cities, approximately one hundred miles from each.

Figure 1 shows in a pictorial manner the chief physical features of the state of Kentucky. The motorist bound southward on the Dixie Highway after leaving Louisville rides for twenty miles or so within sight of the Ohio River and then turning up the valley of the Salt River soon enters the "Knobs" region. These Knobs are simply outliers or remnants of Muldraugh's Escarpment, the margin of the Mississippian Plateau. Muldraugh's Escarpment is sometimes called Muldraugh's Hill, and the Mississippian Plateau often has the name Pennyroyal Plateau.

A long grade on the Dixie Highway is encountered after passing the town of West Point, and amidst rather bold and imposing scenery the motorist finds himself after a few miles on top of the rolling upland, the Mississippian Plateau. This upland continues without interruption almost to Nashville where descent is again made to the floor of the Nashville Basin, a district in many respects similar to the Blue Grass region of Kentucky.

On the railroad the ascent to the top of the Pennyroyal Plateau over Muldraugh's Hill is made a few miles south of the highway near the station called Tunnel Hill. From Elizabethtown south the highway and railroad parallel each other. This is due to the fact that the great route of travel from north to

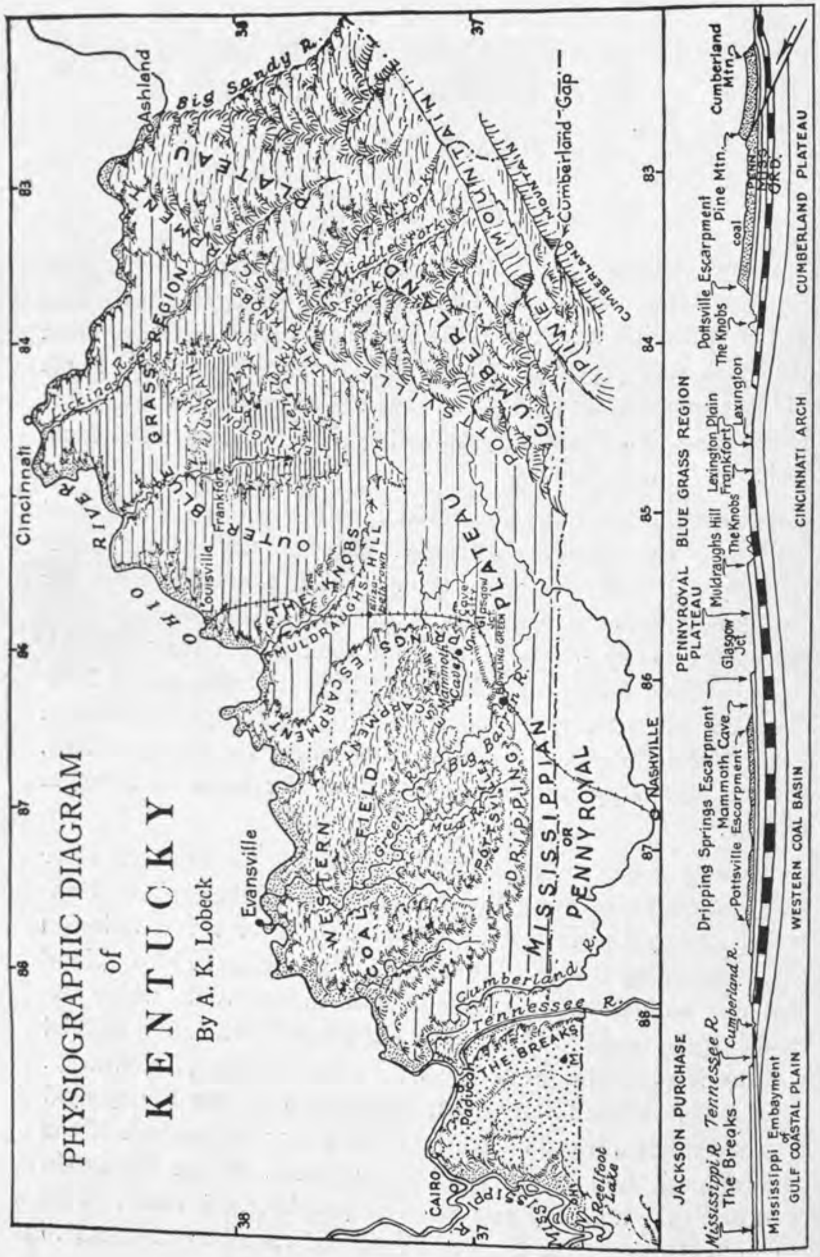

FIG. 1. PHYSIOGRAPHIC DIAGRAM OF KENTUCKY WITH GEOLOGICAL CROSS-SECTION

Mammoth Cave is situated about half way between Louisville and Nashville, in a hilly plateau region a few miles west of the Dripping Springs Escarpment.

south across this region could not follow a direct line to Nashville because of a second plateau rising up to the west, the margin of which is called the Dripping Springs Escarpment.

FIG. 2. THE PENNYROYAL PLATEAU NEAR CAVE CITY

This is a typical part of the Pennyroyal, with an outlier of the Dripping Springs Escarpment in the distance. The Pan-American, through all-Pullman train of the Louisville and Nashville Railroad takes a siding here to pass its sister train bound south for New Orleans.

All routes of travel were forced to keep farther east than they would normally go and consequently we find highway, railroad, and many villages lying close to its base all the way from Elizabethtown to Bowling Green.

Among these towns is Cave City, at which point the motorist turns toward the west and, rising over this second escarpment, finds himself after ten miles at Mammoth Cave. In a similar manner the traveller by train, leaving the main line at Glasgow Junction transfers to the little branch railroad (Figure 3) which for the first few miles experiences steep grades in its ascent to the plateau in which Mammoth Cave is situated (Figure 24).

It must not be imagined that the Mammoth Cave Plateau region (Figure 4) west of the Dripping Springs Escarpment* resembles very closely the Pennyroyal Plateau. The Pennyroyal Plateau (Figure 2) on the one hand with its many roads and railroads, its frequent towns and villages, its extensive farms

*Recognized and named as a physiographic feature by W. R. Jillson, Pan-American Geologist, Vol. XLII, August, 1924.

and broad cultivated tracts, presents a pleasing rolling surface, somewhat prairie-like in its general aspect. The Mammoth Cave region, on the other hand, is ever so much more rugged in its relief. Most people would describe it as being quite hilly. Much of the region is still in woods and waste land. The presence of the many caves would perhaps at first hardly be suspected although, as a matter of fact, a person familiar with cave regions elsewhere would notice certain features in the landscape

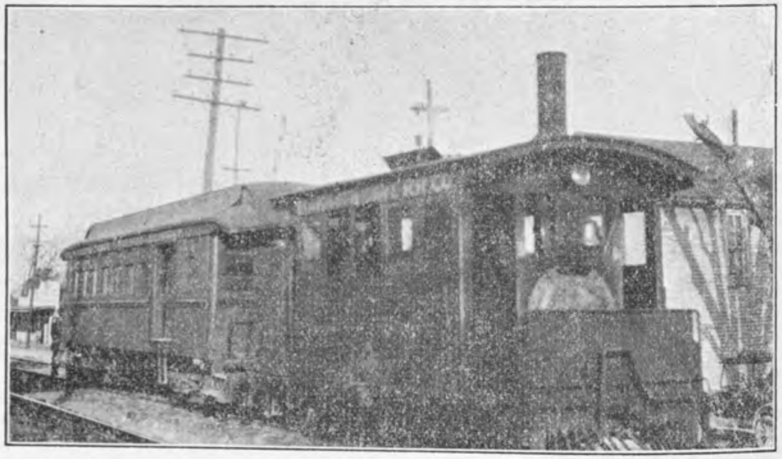

FIG. 3. TRAIN ON MAMMOTH CAVE RAILROAD AT GLASGOW JUNCTION

which would tend to suggest their presence. Most obvious of these external features are the numerous sinks or depressions, the so-called "valley-sinks", or extensive valley systems without outlets, the almost entire absence of surface streams, the occasional exposure of limestone formations revealing solution cavities, and even the presence on the surface of the hillsides of cave deposits due to the collapse of parts of caves along the valley slopes.

Before entering upon a discussion of the meaning of the various details to be seen here it will probably be more interesting to review the broader aspects of the Park area in order to gain a picture of the region as a whole. This will be followed by an explanation of the geology and physiography of the region, after which the caves and the various cave deposits will

FIG. 4. GENERAL VIEW OF MAMMOTH CAVE NATIONAL PARK AREA

The valley of the Green River lies several hundred feet below the plateau surface. To the left is the region of caves, to the right is the rugged hill country north of the river.

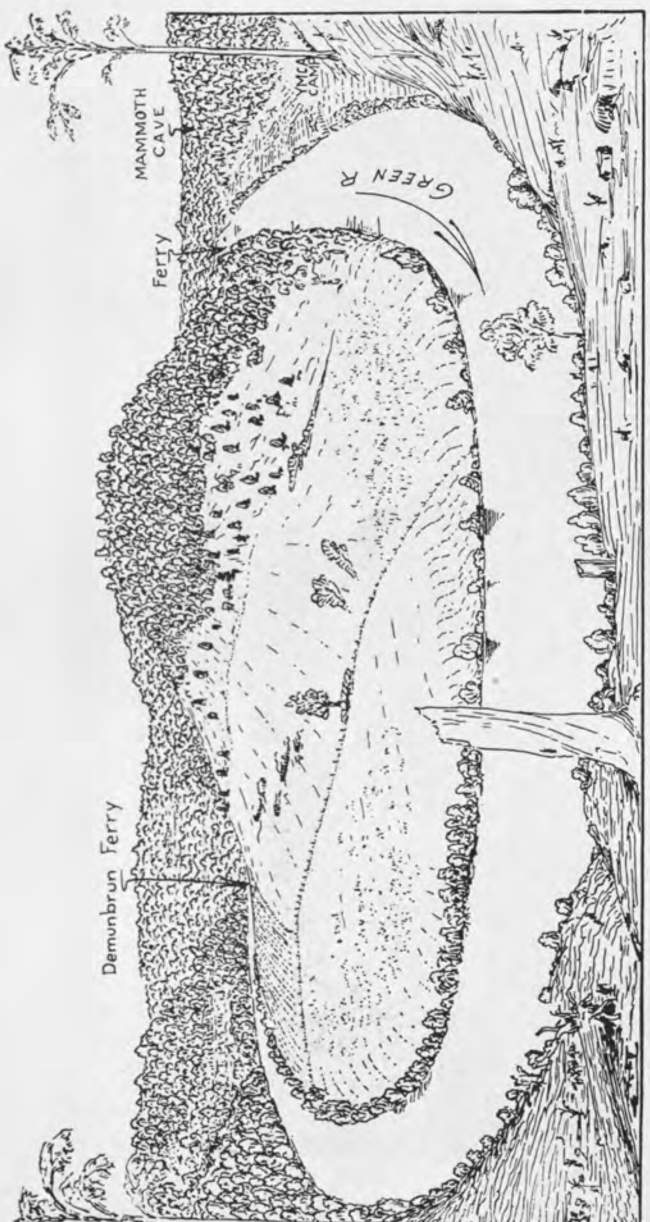

FIG. 5. LANDSCAPE SKETCH OF GREEN RIVER GORGE, BELOW MAMMOTH CAVE

The river here is entrenched 300 feet below the plateau, and at this point swings in a majestic arc whose radius is about one-half mile. The bluffs on the outside of the bend upon which the observer stands are steep, almost vertical cliffs, with outcrops of limestone and sandstone. Across the river, on the inside of the bend is an alluvial flat whose elevation is approximately 40 feet above the river level. These flats date probably from glacial time and represent deposition made by Green River to keep pace with the deposition made by the Ohio. Such flats are cultivated wherever they occur. The slopes directly back of them are usually gentle and show limestone outcrops, and are covered with residual limestone soil. When cleared they rapidly develop gullies but as soon as the soil is removed so that the water can reach bed rock limestone, into which it quickly disappears, downward cutting no longer proceeds and gullying practically ceases. The upper slopes, even when not cliff-like, are almost invariably left in timber which consists at the top, where the sandstone capping conserves the water supply, of deciduous or broad-leaved trees, but farther down on the lower limestone slopes pines and cedars are prominent.

be described. Finally, in order to round out the picture, a few words will be devoted to the activities of the people who now abide in this area.

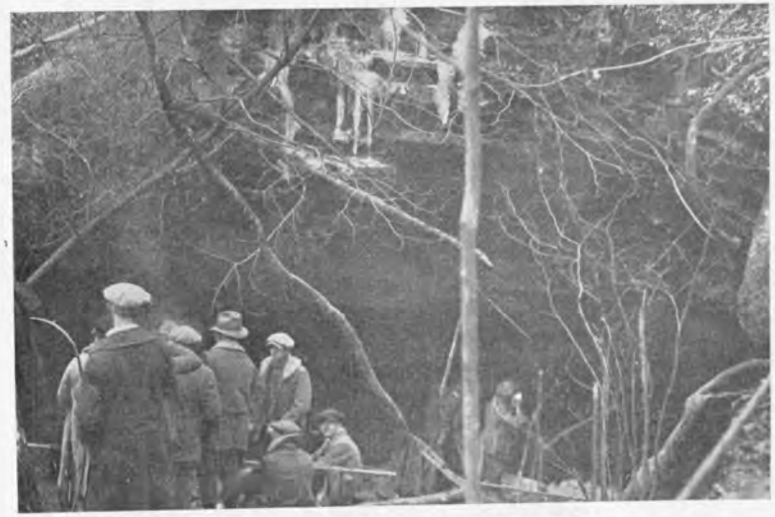

FIG. 5a. ENTRANCE TO SAND CAVE

This photograph was taken at the time the Floyd Collins rescue was in progress. Note the icicles on the ledge above. The worst of weather conditions operated to delay Collins' recovery until after his death. Meanwhile one of the greatest individual human interest stories was developed day by day by the American Press. Collins' grave is within the Mammoth Cave National Park boundary.

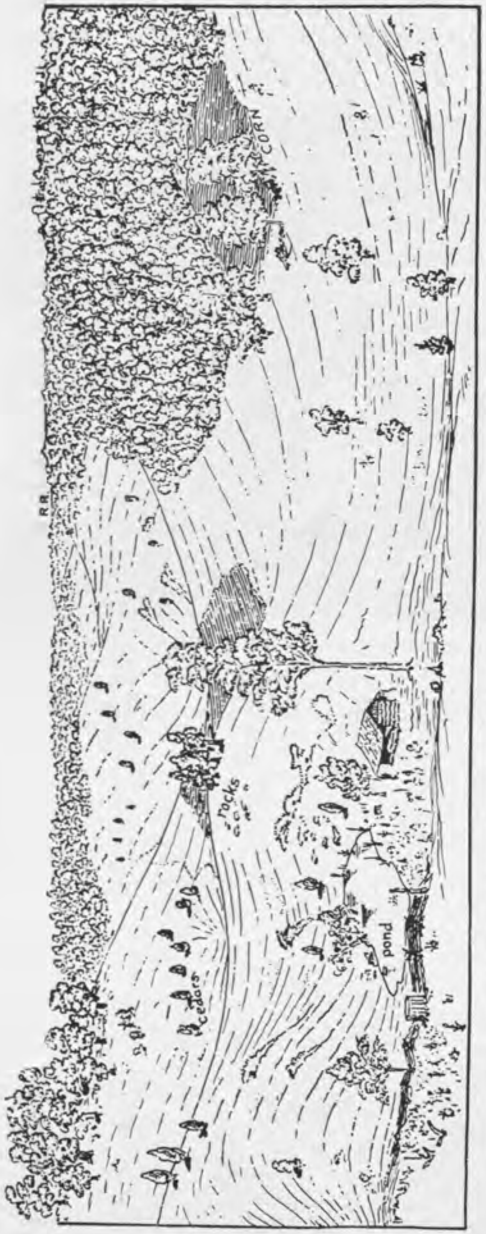

FIG. 6. LANDSCAPE SKETCH OF DEER PARK, A VALLEY SINK

This typical medium-sized valley sink, as a whole, has a branching system like most valleys. Its floor, however, is not a single depression. In the immediate foreground, for example, is a minor sink containing a pond. Many of the depressions are flat at the bottom, being covered with a layer of clay washed in from the sides, but there are many cases where this is not true and then the sink is cone-shaped. The bottoms of the sinks and many of the lower slopes are cultivated for corn and tobacco, these being the sole crops in the valley sinks. Where not cultivated there are open meadows with scattered trees and small shrubs. It is in this more or less open zone that cedars abound, and because of the park-like aspect thus produced gives the name Deer Park to this particular valley sink. The higher and steeper slopes which are in the upper limestone and in the sandstone horizons are invariably in forest which consists of oak and other deciduous trees including hickory, chestnut, tulip, sycamore, red bud, dogwood, and ironwood. Willows grow around the ponds occupying the sinks. There are no running streams in the area, but on top of the plateau above the sink, marshes and ponds may occur and these drain off in little rills which cascade over the sandstone ledges and then immediately disappear into the limestone. Few if any houses are found in the valley sinks, the farms being found on the plateau above which is extensively cultivated. Foxes, rabbits, raccoons, and many birds such as hawks, crows, owls, pileated and other woodpeckers, are commonly seen in these surroundings. No deer, however, live here.

THE MAMMOTH CAVE NATIONAL PARK REGION.

The region which it is proposed to include within the Mammoth Cave National Park embraces an area of over 100 square miles, some 70,000 acres, lying in a rugged plateau country (Figure 4) in south central Kentucky. It is just west of the Dripping Springs Escarpment and on the eastern margin of the Western Kentucky Coal Field. The area is cut into two approximately equal parts by the course of the Green River (Figures 15 and 5). These two parts are, in a general way, dissimilar, both physiographically and culturally. In the southern half lie all the caves of the region and here, too, sink holes and valley sinks abound (Figure 4). Flat-topped plateau remnants (Figures 7 and 8) make up a large fraction of the area although over one-half of the original plateau has given way to the sinks and depressions (Figures 9, 10, 11 and 12). It is under these flat-topped mesa-like pieces of country that the largest caves are found. The northern half is a rugged hilly country (Figures 13 and 14) with few or no sinks except along a belt near the Green River. In the part south of the river practically no streams are encountered even in the larger valleys. The temporary streams do not flow through continuously to the Green River but are interrupted and disappear into the ground. In the northern part the streams are frequent and follow well-defined valleys albeit during some seasons many of them are dry.

The difference between the two areas lies in the fact that a thick limestone formation makes up the southern half of the region (Figure 15) and is accountable for the caves and sinks which occur there. This limestone formation, however, dips gently toward the north and toward the west, and only a few miles north of the Green River it reaches so low a level as to have no effect on the topography. Other higher formations, largely shales and sandstones, overlie the limestone in this northern portion and make up the body of the country. In the most northern parts the limestone has entirely disappeared, even in

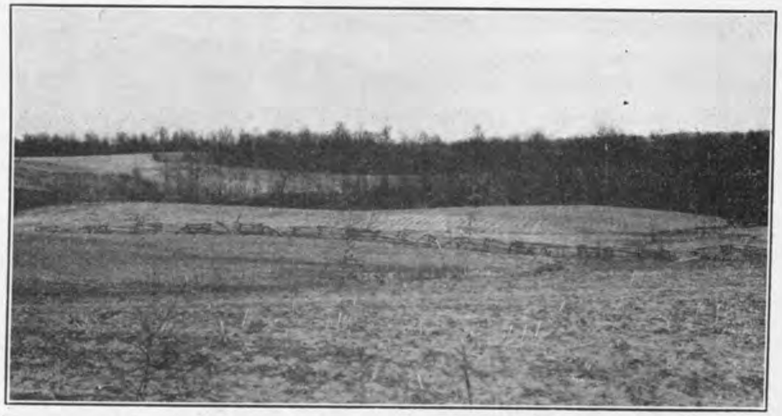

FIG. 7. TYPICAL CULTIVATED UPLAND SURFACE, NEAR CAVE

This landscape is characteristic of the region south of Green River and of a considerable belt just north of it. Corn is the chief crop but oats and hay are also grown. Rail fences are still to be seen but these are rapidly being replaced by wire fences which are much cheaper and more durable.

FIG. 8. POND ON SURFACE OF THE PLATEAU OVER MAMMOTH CAVE

This occupies a very shallow depression, undoubtedly formed by surface water draining through to the limestone cavities below. The outlet, however, has apparently become clogged and some of the water now drains off by a little stream to the plateau margin.

the bottoms of the valleys, and the massive sandstone produces cliffs and valley walls of striking charm and beauty.

Culturally, there is also a noticeable difference in the two areas. This is due largely to the fact that the northern part is distinctly isolated, owing to the presence of the Green River

FIG. 9. POND OCCUPYING A MINOR DEPRESSION IN ONE OF THE VALLEY SINKS

Such small bodies of water are often very temporary, being most common in the springtime when the rainfall is abundant. When they dry up the floor of the sink is flat and usually no opening, well, or swallow hole is to be seen at the bottom.

gorge. It is true that there are frequent small ferries but nevertheless there is not that free and easy communication which is essential if a region is to be kept from having provincial characteristics.

Poor roads and a distinct dependence upon local resources characterize the northern areas (Figures 16 and 17). Automobiles are very infrequently used and travel is largely by horse back or by mules. Even wagons are not used unless necessary. The chief output or cash products of the region are cattle, pigs, and sheep, and these do not require good roads to get them to market. In the southern area, although by no means is the agricultural development to be compared with that in the

Pennyroyal Plateau, it is nevertheless more diversified than in the region across the Green River. The raising of vegetables and chickens for the hotels, and the growing of tobacco and the production of milk leads to a wider range of interests.

This isolation is observable also in the fact that no negroes live in the region north of the river. It is well known that

FIG 10. SINK HOLE WITH POND IN VALLEY SINK AREA NEAR NEW ENTRANCE CAVE

Many of the sinks contain small bodies of water because the outlet at the bottom has become clogged with silt washed down from the funnel-shaped sides. Outcrops of limestone are common throughout the valley sink area.

negroes are to a large extent dependent upon the initiative of the whites. In other words they tend to be parasitic. In localities where large farms and plantations can be maintained and where considerable labor is employed, the negro is at home, ready to work as a laborer for some one else. But he rarely makes a go of it when he has to match his wits against nature under adverse conditions.

The southern half of the area where the caves exist is more or less readily reached from the fertile plains of Kentucky only a few miles to the east. Railroads and roads make cultural influences more immediately felt. There are frequent opportunities for those who cannot succeed on their own account to

work as laborers or road builders, or to find employment in and around the hotels.

It is hoped in the course of the following pages to explain other facts of physiography and culture, but perhaps this bold characterization of the two parts of the Park area will provide the reader at the outset with something tangible upon which to fix his attention.

FIG. 11. A TYPICAL VALLEY SINK
The forested upper slopes, the cultivated lower slopes and the entire absence of habitations are all characteristic of the valley sinks.

FIG. 12. A CHAIN OF SINKS
These are of frequent occurrence and often occupy a narrow valley a mile or two in length. If not too small and steep-sided such sinks are usually cultivated, otherwise they are left in forest.

THE GEOLOGICAL STRUCTURE OF THE MAMMOTH CAVE NATIONAL PARK REGION.

The visitor to Mammoth Cave who knows nothing whatever about geology can, nevertheless, in a few moments grasp the essential facts which are necessary to a real appreciation of the region. Very few places of scenic interest have so simple a design.

Like all the rest of Kentucky, and like many of the adjacent states, this is a part of the vast Interior Lowlands of North America which stood at one time under the sea, and thus received deposits of lime, clay, and silt which accumulated on the sea floor to a thickness of hundreds and indeed of thousands of feet. When the continent was uplifted and the sea drained away to the south, where it still forms the Gulf of Mexico, these layers of rock piled one above the other were raised to form dry land. At first, having the aspect of a flat plain, the appearance of the region gradually changed because of the valleys which were cut into it by the many streams which developed there. Figure 15 shows this in an extremely simple and diagrammatic manner. The upper block portrays the appearance of the region immediately after uplift, and in the lower block may be noted its present configuration.

It will be observed that in this particular locality, when the layers of rock appeared above the sea they were not lying in a strictly horizontal position but were sloping or dipping very slightly toward the north or northwest. This is clearly to be seen in the upper block of Figure 15. In other words, although all of Kentucky is made up of sedimentary rocks such as limestone, sandstone, and shale, these rocks throughout the state do not everywhere lie in a strictly horizontal position but dip slightly in one direction or another. This may perhaps be more clearly understood by glancing again at Figure 1 which shows diagrammatically the physical features of the state of Kentucky together with a cross-section of the underground structure. Examine the cross-section and note that there are essentially four different structural units which make up the state of Kentucky.

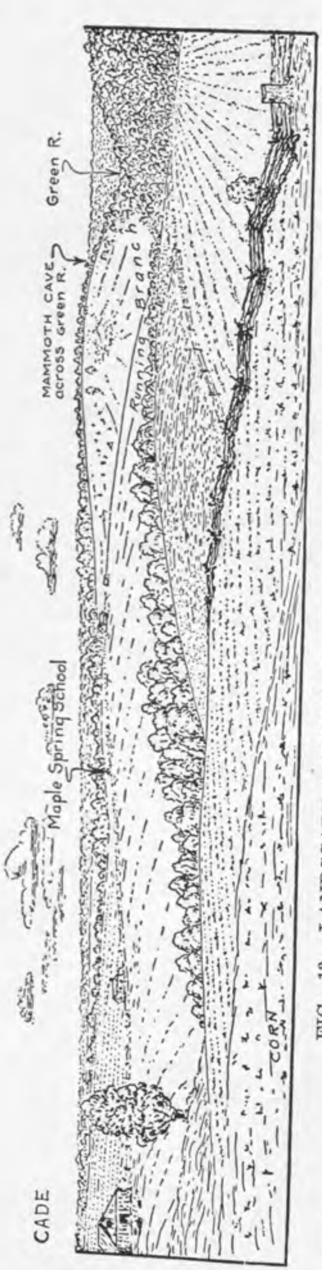

FIG. 13. LANDSCAPE SKETCH OF UPLAND NORTH OF GREEN RIVER

This is a rolling, submaturely dissected plateau with well developed drainage pattern. Considerable flat-topped summit areas remain, usually deeply covered with sandy loam, but residual limestone soils also occur. The roads invariably follow the divides, and here are to be found all the houses of the region. Practically all of the upland is in farms as well as many of the slopes which are quite gentle. The valley sides and bottoms are always wooded.

Named from west to east they are the Gulf Coastal Plain, the Western Coal Basin, the Cincinnati Arch (or Blue Grass Region), and the Cumberland Plateau. The Gulf Coastal Plain and the Cumberland Plateau need not in this connection detain us any longer.

In the Western Coal Basin the rock formations have been warped or bent down slightly in the central part. In the Cincinnati Arch, on the other hand, they have been bent up, as the term arch implies. Geologists speak of the basin area as having the structure of a gentle "syncline," and the arch area as a gentle "anticline." Now it will further be observed when the cross-section and the map are studied together that in the Blue Grass Region where the strata have been up-arched, the top-most formations are no longer present, due to the erosive work of streams, and to the profound weathering and the decay of the rocks during the long time which has elapsed since the region appeared above the sea. The Blue Grass Region, therefore, shows in its central part, which is known as the Lexington Plain, the bottom-most or the oldest rocks to be observed anywhere within the state of Kentucky. This region reminds us very much of an onion with its different layers, the outer ones being cut away at one place so that the inner ones are visible. The rocks of course slope or dip away in all directions from the central or most elevated part of the arch or dome.

In contrast with the Blue Grass Region the Western Coal Basin still exhibits the complete sequence of formations, the upper-most ones being present in the center of the basin. Indeed it is more than likely that the coal-bearing formations of the Western Coal Basin at first continued eastward over what is now the Blue Grass Region and joined on with those of the Cumberland Plateau. The plateau, like the Western Coal Basin, is also a gentle basin in structure.

The next point to be noted is the fact that with the removal of the upper-most formations from the Cincinnati Arch, a series of escarpments was formed. Looked at through the perspective of geological time, the present position of these escarpments is only temporary. Each escarpment retreats or wears back, thus exposing more and more of the lower strata. The several escarpments differ considerably among each other. Some of them

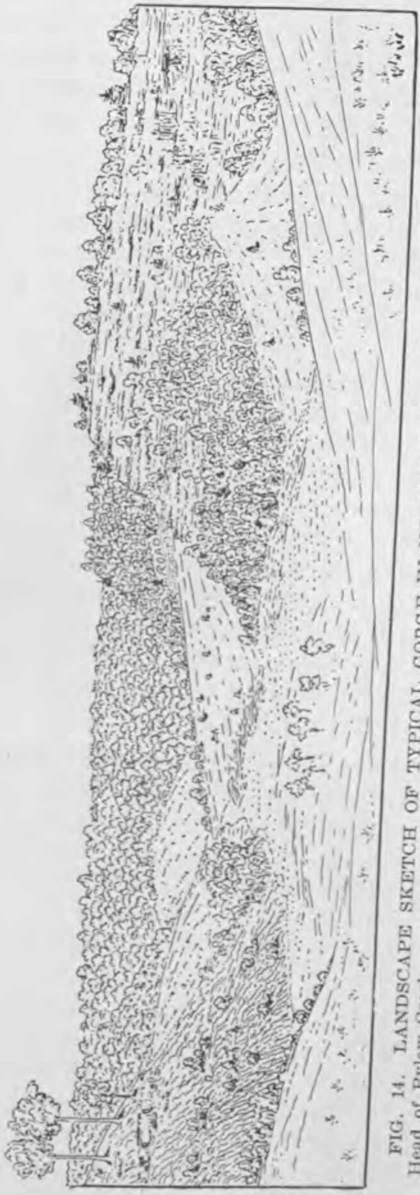

FIG. 14. LANDSCAPE SKETCH OF TYPICAL GORGE IN NORTHERNMOST PART OF THE PARK AREA

Head of Bylew Creek, a young gorge cut into Pottsville sandstone and conglomerate which stands up in many places as vertical cliffs. The floor of the valley has occasional little flat patches. These are cultivated, but are subject to flooding. All moderately gentle slopes are cultivated, but people do not live here because of the inaccessibility. There are no good roads in the valleys but the plateau above is to a large extent developed. Springs issue at frequent intervals from the base of the valley walls.

are so much dissected by streams and ravines as to have a very irregular appearance. Thus the Knobs around the margin of the Blue Grass Region are to be explained. Most of the escarpments, too, are not simple and sharply defined, but frequently hills or outliers stand out in front of the escarpment, the last remnants of the formation which at one time extended continuously to that point.

Between the successive escarpments there stretch broad expanses of country usually called plateaus. The Pennyroyal Plateau is one of the most extensive of these. Some of these plateaus are flat or gently rolling, this being true of the Pennyroyal again, but elsewhere the plateaus are very hilly and rugged because of the many valleys which ramify through them. The Cumberland Plateau is so rugged on this account as to be called "mountains." The reason that a succession of plateaus develops is because the successive formations do not all react to erosion in the same manner. Certain layers like sandstone weather less readily than others and these often cap the plateau surfaces. In Kentucky, however, several of the plateaus are made up of limestone formations.

With these general observations it will now be advisable to turn again to Figure 1 and to note the relationship the Mammoth Cave Region bears to the rest of Kentucky. It is seen to lie on the eastern margin of the Western Coal Field, in the plateau area lying just to the west of the Dripping Springs Escarpment. The formations dip in general northwest toward the center of the coal basin.

We are now ready to examine with a little greater care the details of Figure 15. Five geological formations are shown in the series which make up the area.* Let us note the relationships which these formations bear to the topography. The lowest member of the series is called the St. Louis limestone. It outcrops in the southern part of the area and forms the surface of the Pennyroyal Plateau at Cave City and Glasgow Junction. Next comes the Mammoth Cave limestone followed by the Cypress sandstone. These together make up the plateau area north and west of the Dripping Springs Escarpment. The main mass of

* These formations are further subdivided and additional names are used in detailed geological consideration of the region. See J. M. Weller, Geology of Edmonson County, Kentucky Geological Survey, 1927.

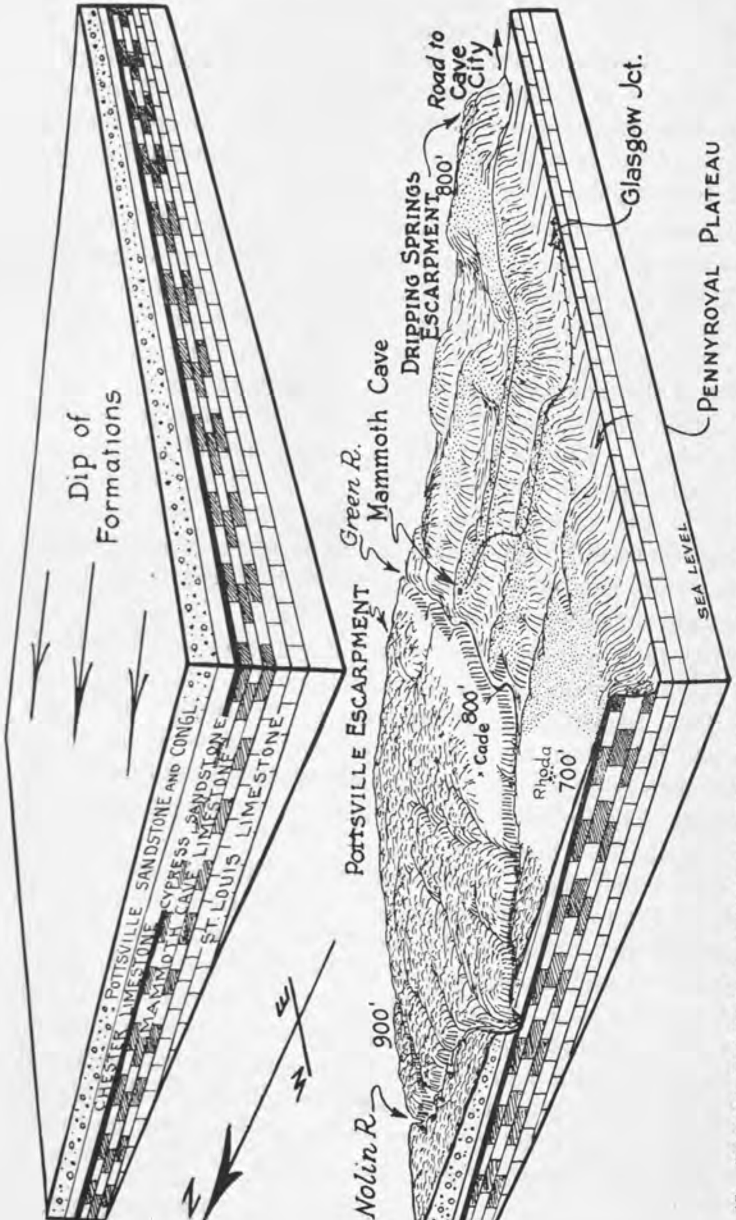

FIG 15. BLOCK DIAGRAMS SHOWING TWO STAGES IN THE DEVELOPMENT OF THE MAMMOTH CAVE REGION. The upper block illustrates the original conditions before dissection has taken place. The lower block illustrates the present configuration of the country. The formations dip toward the northwest.

the plateau is made up of the Mammoth Cave limestone formation which all told is almost 300 feet in thickness. The top of the plateau, however, is capped with the Cypress sandstone. This formation is less than 50 feet thick. In many places it has been worn away so as to reveal the limestone beneath.

At such places as well as along the margin of the plateau, that is, along the front of the Dripping Springs Escarpment, the limestone quickly weathers away. In other words, the Cypress sandstone formation is apt to be undermined more or less. The result is that the Dripping Springs Escarpment retreats or works back in the direction of the dip of the formations, that is toward the north and west; and also that the valleys that form in the plateau widen very rapidly. In consequence of this the plateau has lost its simple plateau-like aspect and is made up of a number of units or tablelands, somewhat like mesas in other parts of the country. It is under one of these mesas that Mammoth Cave is found.

Next above comes the Chester limestone, with some associated sandstones and shales. This series, in places 200 feet in thickness, is as a whole not very resistant to weathering and is apt to be removed from most of the hill tops. Finally, as we get into the hilly area north of the Green River, we find the Pottsville formation making up much of the country. This formation is a sandstone and conglomerate. It has a thickness of several hundred feet in places, depending of course upon the amount that has been eroded. Owing to the fact that all the formations lie deeper and deeper as one goes farther and farther north, it is evident that in the northern-most part of the region only the highest or the Pottsville formation may be observed, even in the deepest stream valleys.

So in the gorge of the Nolin River, in the northern part of the Park area we observe only the bold cliffs of sandstone where that stream has cut its narrow valley through the Pottsville formation. Farther south, in the vicinity of the Green River the Pottsville formation is to be found only on the tops of the hills. In the floor of the valleys may be seem the underlying formations such as the Chester limestone, the Cypress sandstone, or even the uppermost portion of the Mammoth Cave limestone.

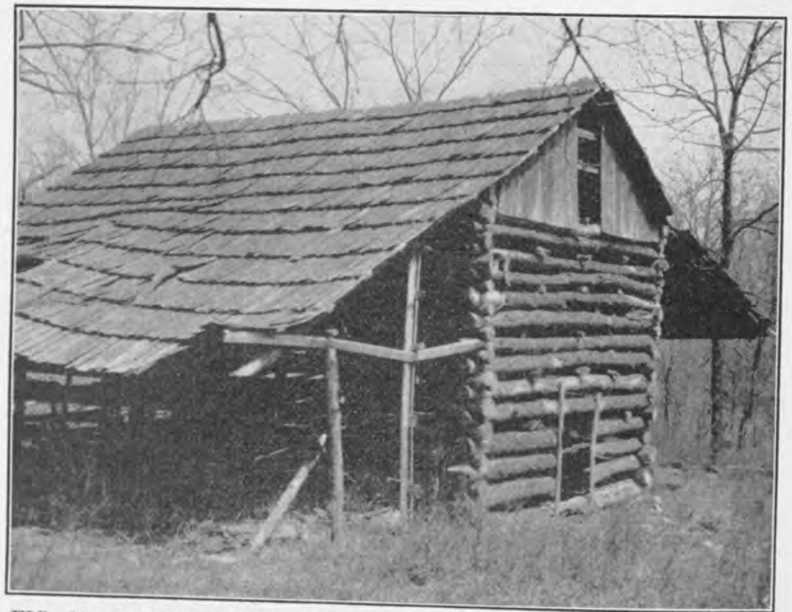

FIG. 16. LOG BUILDING USED FOR STORING CORN AND SHELTERING LIVE STOCK

All the material used in the construction of this building has come from the immediate locality.

FIG. 17. AN OLD HOMESTEAD

Several buildings of this type are still to be seen in the region north of the Green River. Practically every part of this building has been produced on the premises. This is still true of buildings more recently constructed, except that the introduction of portable saw mills has made it possible to use finished boards more extensively.

THE PHYSIOGRAPHY OF THE MAMMOTH CAVE NATIONAL PARK REGION.

The area to be embraced in the Mammoth Cave National Park is transected by the gorge of the Green River which, from the standpoint of physiography, divides it into two contrasting sections. The contrast in the physical appearance of the two regions is due largely to the fact that in the portion north of the Green River the present configuration of the country has been produced by the erosive activity of streams of water flowing on the surface of the ground, whereas in the portion south of Green River the present forms of the land have to a large degree been affected by the fact that most of the drainage of the region sinks below the surface and flows off through underground channels. Figures 18 and 20 are designed to show diagrammatically the contrast that results from these two opposing conditions. Each of the figures depicts four stages in the life history of the kind of region which it illustrates.

Life history of plateaus having surface drainage. Figure 18 has to do with a region made up of sedimentary rocks that lie in an approximately horizontal position. These rocks include sandstones, shales, conglomerates, and limestones. The limestone layers, however, are not anywhere of very great thickness, nor of exceptional purity. In other words, this illustrates a typical part of the extensive plateau area which is embraced in the eastern United States. The Western Coal Basin of Kentucky is a plateau of that type. Observe now the appearance of such a region during the successive stages of its development.

Youth.—In the top-most block we note two streams flowing across the area which has the aspect of a plain. The valleys have not yet cut very deeply, nor are they very numerous. Much of the surface is as yet unaffected by the activities of erosion. Such a region is said to be young.

Late youth or submaturity.—In the second block we note that there are more streams, that the streams are longer because they have, after the manner of gullies, worked headward into

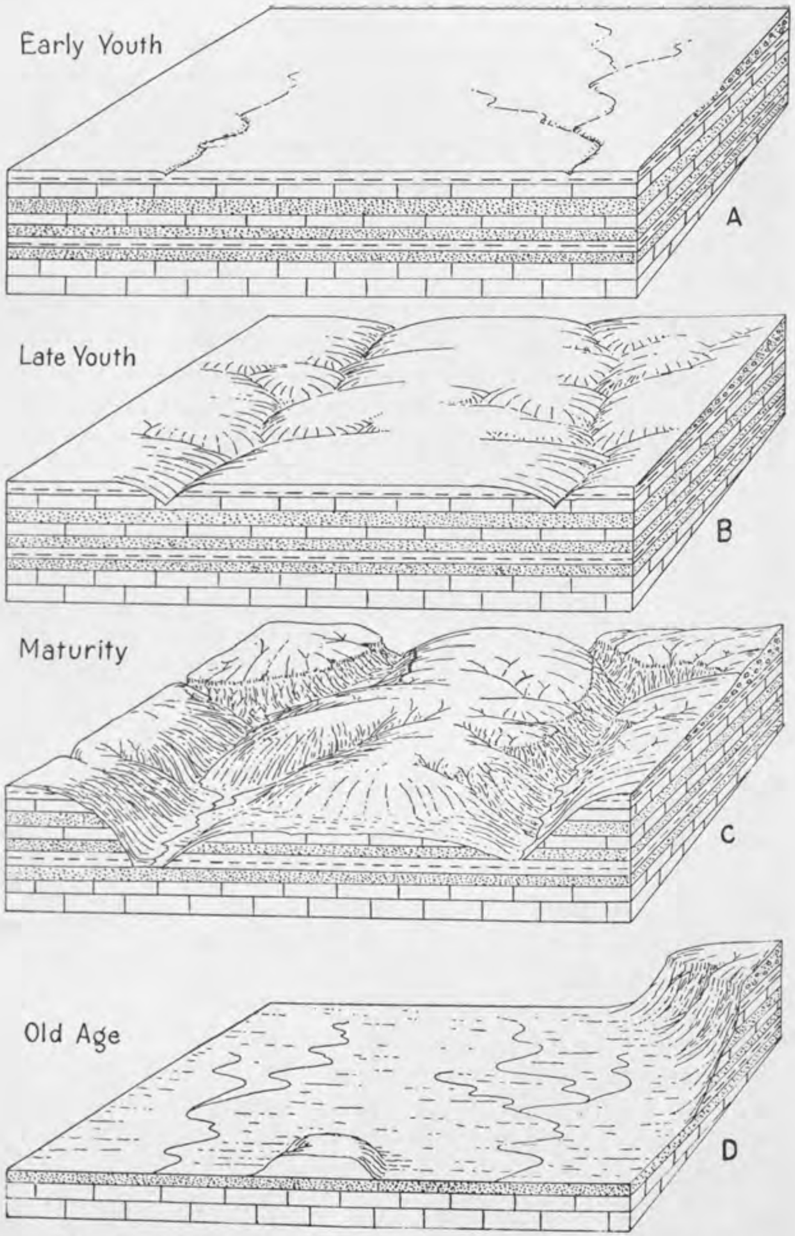

FIG. 18. FOUR STAGES IN THE NORMAL LIFE CYCLE OF A PLATEAU

The plateau here represented is made up of sedimentary rocks of several types. Surface drainage prevails throughout the region during the entire life cycle. The features illustrated here are discussed in detail in the text.

the plateau in all directions, and in addition we note that the valleys are deeper. There are still, however, broad spaces between the streams which are flat and undissected; that is to say some of the original surface of the plateau still remains. Such a region is said to be submature, that is, not quite mature. Some of the Allegheny Plateau in northern Pennsylvania is in this stage, but most of the plateau areas in Kentucky have advanced to maturity.

Maturity.—In maturity, the region reaches its most rugged condition. Streams ramify into all parts so that the divides between the valleys are comparatively narrow. There may be gently rolling upland areas but they are by no means extensive. The valleys are deep, even gorge-like, and in many places the valley walls may exhibit vertical cliffs of rock where harder formations like sandstone have been cut through by the streams. At this time, too, one may note a tendency for the larger streams to widen the floors of their valley and thus occasionally to provide here and there small stretches of bottom land which can be cultivated. Different kinds of rocks may appear in different places on the uplands between the streams. This may be due to the fact that the formations dip slightly in one direction as shown on the right hand side of block C in Figure 18. The region north of Green River in the Mammoth Cave National Park area presents all of the aspects just enumerated for the mature stage.

Old age.—After maturity is passed the streams develop still wider valley floors, the hills become much smaller, and eventually we find the conditions represented in block D. This is practically the state of affairs found in the heart of the Blue Grass district and to the east and south of the Park area. The Pennyroyal Plateau represents an area from which the overlying formations have been stripped. The Dripping Springs Escarpment represents the edge of those higher formations, that is, the margin of the plateau. Outliers of this plateau stand as isolated hills out on the Pennyroyal (Figure 2.) A region, then, which has by a long period of erosion been worn down to an extensive plain, like the Pennyroyal, is said to be in old age. The Pennyroyal, however, has started another period of devel-

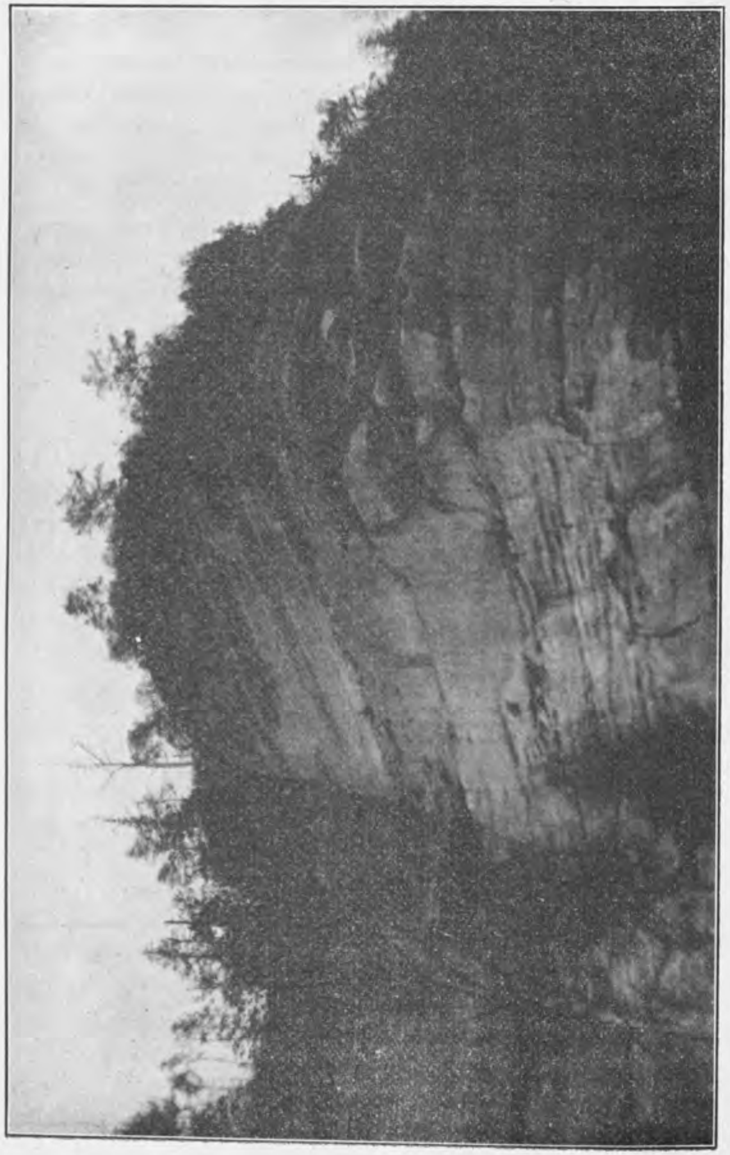

FIG. 19. DISMAL ROCK ON NOLIN RIVER

Features of this type are characteristic of the northern part of the Park area where the streams have cut steep-walled gorges through the Pottsville sandstone formation. The sharp flat faces of the cliffs are due to the joint planes of the rock.

opment. As a result of uplift of the region its streams are again cutting into its surfaces. In other words, it has been rejuvenated and is starting another life cycle. Nevertheless, in its main aspects, it presents many of the characteristics of an old plain like that portrayed in block D in Figure 18. A few pages farther on under the discussion of old age brought about by underground drainage it will be shown that the Pennyroyal Plateau more accurately belongs in that classification. It is described here, however, because it is so good an example of a region at one time in old age, and is near the Park area where everyone will see it.

Description of the National Park area north of Green River. If the visitor to this region crosses the ferry just below Mammoth Cave and ascends the plateau north of Green River in the vicinity of Maple Spring School and Cade he will see spread before him for several miles in all directions a rolling upland surface (Figure 13). Valleys appear everywhere but they are not so numerous nor so large as to destroy the effect of the upland. This phase of the region is represented in block C in Figure 18. The plateau is there capped with a sandstone called the Hardinsburg, this being included in the series marked Chester in Figure 15. Just beneath the Hardinsburg sandstone is a limestone formation not of very great thickness. It accounts for the several sinks to be noted near Maple Spring School and Cade. This is the only place north of the river where sinks of any size are to be seen. The reason, of course, is evident from the structural facts given in Figure 15, where it is to be observed that the limestone dips away toward the north and west and disappears beneath the overlying Pottsville formation. This portion of the plateau with its fairly wide interstream areas or uplands might be termed submature in its stage of development. A characteristic view over this region is shown in Figure 13. This view portrays the rolling upland, almost everywhere cleared and cultivated. The valleys and the sinks remain wooded. The main roads invariably follow along the comparatively level divides and in that way one can travel for miles without descending into the valleys. This region is, as a matter of fact, by far the most prosperous part of the belt lying north of Green River. This is

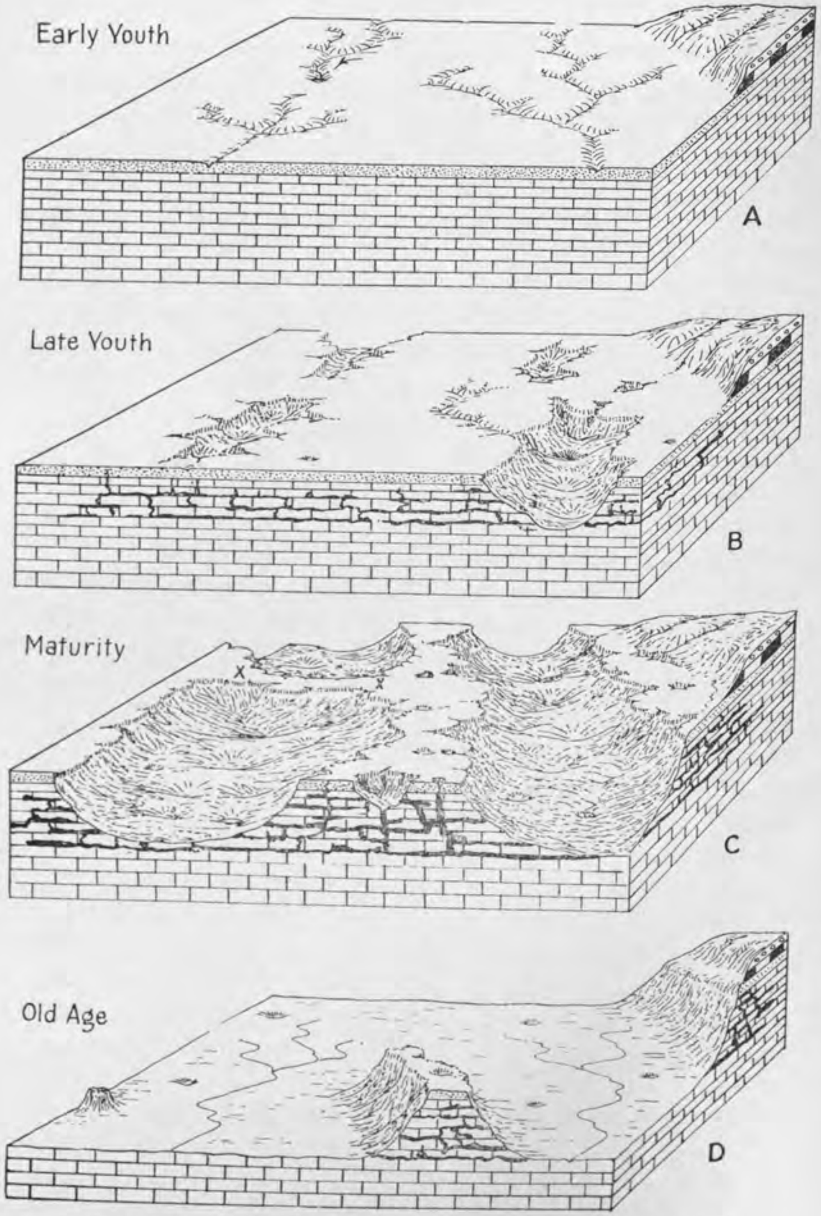

FIG. 20. FOUR STAGES IN THE LIFE CYCLE OF A PLATEAU HAVING UNDERGROUND DRAINAGE

The plateau here represented is made up largely of limestone. Except for the earliest and latest stages surface drainage is almost entirely absent. See text for detailed description.

due to the much more extensive level topography, in contrast with the region lying still farther north, as well as to the much better soil, this being a sandy loam derived from the decay of sandstone and limestone, whereas the soils of the northern area, derived from the decay of the Pottsville formation, are sandy and gravelly, very open, and on that account so dry as not to yield good crops.

North from this point the tops of all the hills are capped with formations overlying those to which reference has just been made. The hills are much bolder, the valleys are deep, often gorge-like, and the uplands, although still constituting the chief inhabited parts of the area, are narrow and often very irregular and knobby.

Some of the most charming scenery is to be found in the northern-most part of the district where Nolin River, one of the affluents of the Green River, together with its tributary Bylew Creek have cut sharp-walled gorges below the upland surface (Figure 14). The sharp, vertical, rock cliffs of these gorges are due to the massive sandstone layers which make up the Pottsville formation. In some places the gorges have flat bottoms and here little cultivated patches of land are occasionally to be found. The numerous side ravines often head in steep-walled coves or amphitheaters, wild and picturesque in the extreme. Dismal Rock on Nolin River (Figure 19) is a part of the valley wall projecting a bit more than usual. On the side nearest the river a tall chimney-like portion is almost entirely detached from the main ledge, this being due to a joint or fracture, a feature common in all massive formations.

Life history of plateaus having underground drainage. Figure 20 has to do with a region made up of sedimentary rocks that lie in an approximately horizontal position. The great body of the plateau is made up of a massive, relatively pure limestone with a little capping of sandstone at the surface. This thin layer of sandstone is introduced into the drawing in order to simulate as closely as possible the conditions in the Mammoth Cave region. As a matter of fact there might be several layers of shale and sandstone and perhaps interbedded limestones, overlying the massive limestone. It is essential, however, that there

be a thick soluble limestone formation in order that subterranean drainage may bring about the usual succession of events.

Youth.—In youth, exactly as in Figure 18, we find streams coursing across the region. The valleys are shallow and the tributaries infrequent. This results in extensive flat areas or

FIG. 21. SMALL SINK HOLE WITH SWALLOW HOLE AT THE BOTTOM

Many sink holes, instead of containing ponds at the bottom, show channels of erosion and an opening or well through which the water disappears underground. Sometimes these openings or swallow holes become clogged and a pond results.

plains. One or two departures from the normal process of erosion, however, may be noticed. The stream at the right in block A Figure 20 is exactly like the corresponding stream in Figure 18. But the stream at the left is commencing to be dismembered and to be broken into detached segments. This is due to the fact that it has in several places cut through the capping sandstone layer and this has permitted the water to penetrate immediately into the joints and bedding planes of the underlying limestone. In other words underground drainage is being inaugurated. In its earliest stages there are still some streams on the surface of the ground, and the sinks or swallow holes through which they find a way to underground cavities are neither large nor numerous.

Late youth or submaturity.—As youth advances, more and more of the drainage goes underground almost as soon as it

falls on the surface. The sink holes rapidly enlarge. At first they are small and funnel-shaped. Often at this stage they contain little ponds either permanent or temporary (Figures 9 and 10). That is due to the fact that the underground cavities at first are small and easily become clogged with the soil washed in from above. This may cause an accumulation several feet in thickness on the floor of the sink. In time, however, the water which seeps through the bottom of the sink dissolves away a larger channel underground and a real swallow hole is formed in the bottom of the sink. Such a feature is clearly illustrated in Figure 21. The accumulated silt in the floor of the sink is rapidly being carried underground, and in this manner a gaping hole or well is produced. In fact, the entrance to the underground channels can sometimes actually be seen in the layers of limestone rock which are thus exposed.

Maturity.—In full maturity the region has lost practically all of its surface streams. Underground passageways have become very extensive. The whole region is honeycombed with a great network and labyrinth of channels and passageways which constitute the caves. The various forms assumed by these features deserve special treatment and will be taken up in the next chapter. The numerous small sinks have been replaced by a few depressions of large size. These are usually called valley sinks or hollows. They may be several miles long and of great depth. The floor of these large hollows is not yet flat but is undulating and is interrupted by frequent sinks and swallow holes. The drainage of the entire area finds its way into these holes, though occasionally there is a certain amount of gullying of the slopes leading thereto. These large depressions are formed by a gradual enlargement of the smaller ones through solution at the bottom and by the washing of material down the funnel-like sides. Different sinks in that way come to be united. It is sometimes stated that sink holes or depressions like those just described have been formed by the collapse of huge caverns, but it is now known that this is practically never the case; at least collapse does not occur over any appreciable area. Sometimes just beneath a sink where the water has been concentrated an exceptionally large passageway may be formed, usually a

vertical channelway. There the floor of the sink may break through and the sink thus enlarged and its walls made somewhat more precipitous. But this, of course, is only of very local importance. Occasionally natural bridges may be formed in this manner but as a matter of fact in the Mammoth

FIG. 22. ENTRANCE TO MAMMOTH CAVE
This entrance is in a ravine leading down to Green River. Many cave entrances are on the sides of the valley sinks.

Cave Region no natural bridges of this kind are to be found. There are, however, certain archways and passageways in the caves which are designated as natural bridges.

It will also be noted that the valley sinks usually have a branching form like any valley. This is due to the fact that small rivulets from the adjacent uplands that still remain are constantly cutting into the upper ends of the ravines and causing them to advance headward. These little rivulets usually appear as springs on the top of the plateau areas, as shown in block C Figure 20, and, after plunging over the steep valley wall, which in its upper part is capped by sandstone, disappear immediately underground upon striking the underlying limestone beds. Large springs are occasionally found near the base

of the cliffs around the margins of the valley sinks at places where the subterranean streams emerge for a moment before again plunging underground in the bottom of the sink.

Practically all of the entrances to the different caverns of the Mammoth Cave Region are to be found along the margin of

FIG. 23. ENTRANCE TO GREAT SALTS CAVE
This entrance is in the bottom of a large sink, not in the center but over at one side. Horse Cave at Horse Cave city is entered in the same way but this means of entrance is uncommon.

the plateaus where the underground drainage channels make their appearance in the walls of the valley sinks or along the valley of the Green River (Figure 22). Sometimes caves are entered through sink holes (Figure 23), never in the very bottom

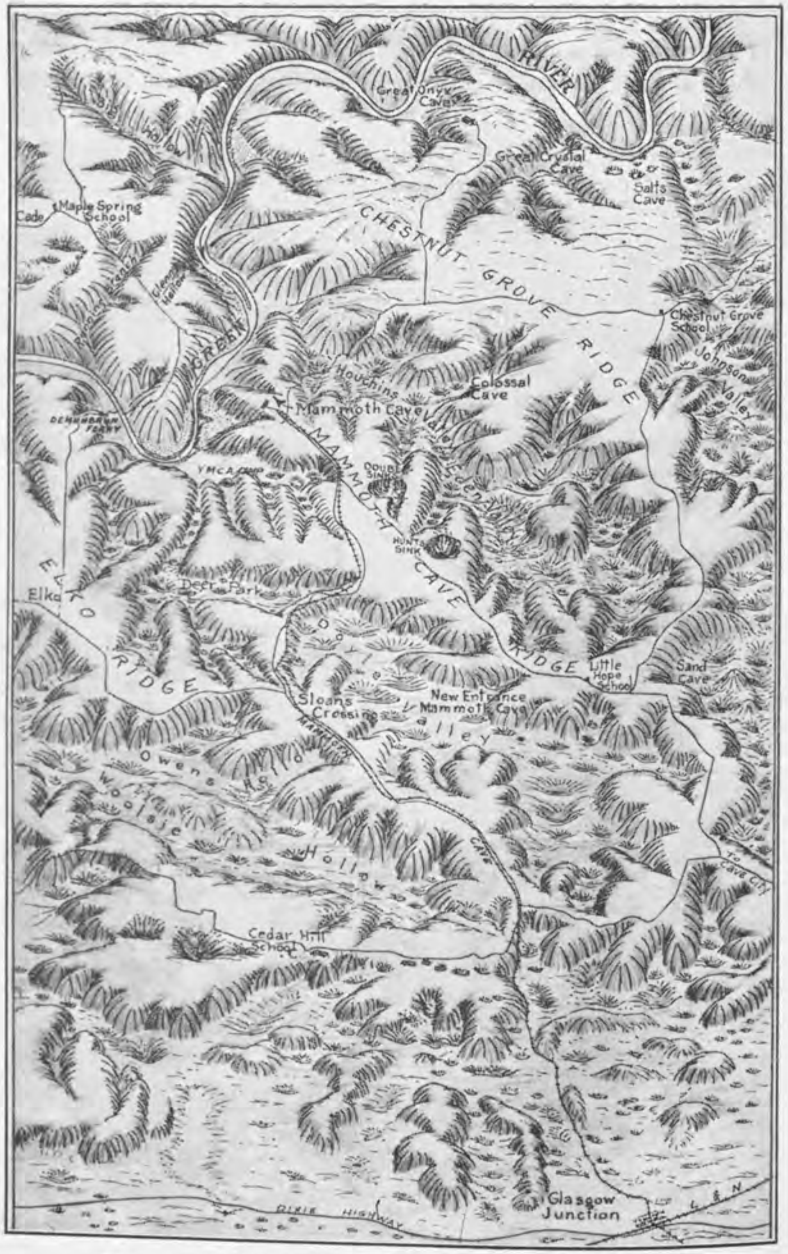

FIG. 24. THE MAMMOTH CAVE REGION IN DETAIL.
This is a modification of the Mammoth Cave topographic map on which the features are shown by contour lines.

of the sink but over at one side because the bottom is usually filled with debris washed down from the surrounding rim.

Old age.—As a region having underground drainage advances from maturity to old age the valley sinks increase still further in size. The plateau remnants between the sinks at the same time become smaller and smaller until only occasional knobs remain above the more or less level country which now prevails throughout the region. These knobs are often flat-topped like those near Glasgow Junction, but in some parts of the world they assume more or less a conical shape and are known as haystack or pepino hills, this being the case in some of the limestone tracts of the West Indies.

With the increase in size of the valley sinks and a gradual dissolving away of the limestone hills which still cover the floor of the sink there comes a time when the underground drainage lines are exposed to view. That is to say, surface drainage is again gradually introduced. This condition may result either because the massive limestone layer has been entirely removed and the underlying beds are impervious in character, as suggested by the cross-section in the front part of block D Figure 20, or on the other hand, even if all the limestone is not dissolved away, nevertheless it may be that no more can be removed because the region has now been brought down to the level of the major streams of that area. With the complete development of old age with its surface streams the region resembles very closely one in old age whose development has been attended by surface streams throughout its whole history.

The country may now be rejuvenated, perhaps by the deeper cutting of the major streams of the region, and the consequent lowering of ground water level. This means then, that if limestones are still present new sink holes will form and the life history of the region will start over again. That portion of the Pennyroyal Plateau near Glasgow Junction displays exactly these phenomena, and for that reason is best classified here as a region that has reached old age during the subterranean cycle of erosion but shows evidences of rejuvenation in its present pitted surface. Other parts of the Pennyroyal, however, are of the more normal type previously described.

Description of the National Park area south of Green River. This section of the Park is of course the part that holds most of the features of interest. Figure 24 shows part of the area in detail. It will be noted that the region consists of several long plateau-like ridges, trending in a northwest-southeast direction, separated from each other by extensive valley sinks or hollows. No streams are to be seen in the area except on the flanks of Chestnut Grove ridge north of Mammoth Cave, and that is because this hill still retains its thick capping of the higher impervious formations overlying the limestone. Most of this region, in other words, is a plateau where underground drainage has brought about the present features, and where the mature stage of development has been reached. It is like block C in Figure 20.

The plateau ridges.—Three ridges in particular deserve to be noticed. In the center is Mammoth Cave ridge which throughout its entire length is followed by the highway from Cave City. North of this is Chestnut Grove ridge, somewhat higher than Mammoth Cave ridge in its northern part because of the capping of higher formations, but it is quite flat farther south and joins onto Mammoth Cave ridge near Little Hope School. The third or Elko ridge extends south and east from Elko toward Glasgow Junction. It is followed by the Mammoth Cave Railroad from Glasgow Junction to Sloans Crossing, at which point the railroad crosses over a narrow divide to the Mammoth Cave ridge. This divide corresponds with the feature marked X in block C of Figure 20. Several others of similar character are to be noted. Perhaps in time, ages from now, a natural bridge will develop at that point as the sinks on either side are deepened and the underground drainage lines come to view.

Beneath each of the plateau areas there is an extensive system of channels and passageways which constitute the caves for which the region is famous. Mammoth Cave extends for many miles beneath Mammoth Cave ridge. It can be entered from several points around the margin of the plateau. Various entrances known and used at earlier dates have been filled in and obliterated to prevent intrusion. There are undoubtedly many places where one could, with the removal of some of the talus material, gain entrance to some part of Mammoth Cave in this

manner. The presence of bats, and of insects which spend part of the time each year on the surface of the ground, and also accumulations of debris, leaves, and other parts of plants in remote sections of the cave suggest the proximity of small openings through which these animals and this material have gained access to the underground channels. The New Entrance to Mammoth Cave was developed by removing material from the surface at a point near a known part of the cave. It is several miles distant from the main entrance to Mammoth Cave and visitors through either entrance never explore those portions of the cave tributary to the other entrance. The statement is frequently made that Mammoth Cave has over 150 miles of explored passageways. As a matter of fact it probably contains hundreds if not thousands of miles of channels of all sizes, for this limestone mass is literally honeycombed with openings.

Beneath Chestnut Grove Ridge there is undoubtedly a maze of caverns perhaps even more extensive than that under Mammoth Cave ridge, because of its greater size. Several well-known caves have been opened up around its margin. Colossal Cavern just across Houchins Valley from Mammoth Cave is entered from the side of the valley sink under conditions very much like those at the New Entrance Cave. Mammoth Cave, however, gains its entrance in a little ravine which descends toward Green River from the western end of Mammoth Cave ridge. Great Onyx Cave on the north side of Chestnut Grove ridge is like Mammoth Cave in that respect. The entrance to Great Onyx Cave overlooks the immediate gorge of Green River. It was discovered by the presence of cave deposits, that is, the so-called onyx of stalactite formations on the surface of the ground, and this was believed to indicate the nearby presence of a cavern which had slumped in along this steep valley wall.

Great Crystal Cave has a similar entrance along the side of Green River gorge. Great Salts Cave, unlike most of the caves of the region, is entered through the side of a steep-walled sink of the region, is entered through the side of a steep-walled sink This sink, however, really represents the upper portion of a valley of a stream which flowed at one time toward Green River, but whose headward part has already become detached by the development of a sink hole. There are several other similar

sinks in this immediate region. There are several other caves too. These are undoubtedly all parts of a vast system of underground openings. Salts Cave vies with Mammoth Cave in the size and extent of its many passageways.

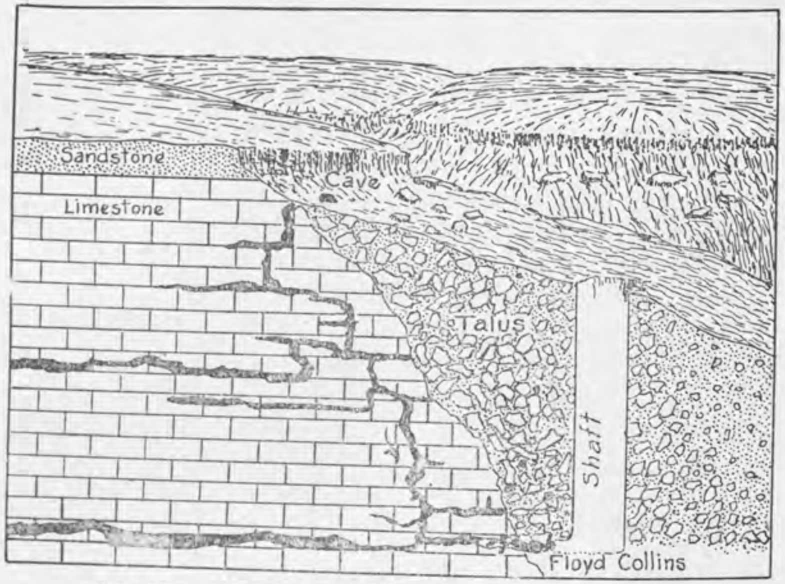

FIG. 25. GEOLOGICAL CONDITIONS AT SAND CAVE.
This diagram shows that Floyd Collins was trapped not in the cave but in the loose talus material on the side of the hill through which he was trying to work his way. The shaft by which his body was later removed was put down through this loose debris.

Sand Cave, in which Floyd Collins lost his life, is entered on the north side of Mammoth Cave ridge not far from Little Hope School. As yet it hardly deserves to be called a cave inasmuch as the passageways are so small and tortuous as to preclude its visitation by tourists. An explanation may here be given as to the reason Floyd Collins was trapped underground at this point, and also why it was possible to construct a shaft from the surface to the vicinity of his body. Figure 25 shows diagrammatically a section of this part of the plateau. There is nothing peculiar about the region. It is like miles and miles of plateau margin. Underground passageways abound. Some of them are horizontal, following the bedding planes, others are more or

less vertical, following joints which have been enlarged by the solvent action of water.

The slope of the plateau toward the valley sink is made up of loose fragments broken from the plateau margin. This is common everywhere. It is the way the plateaus are destroyed and the valley sinks increase their area. Floyd Collins penetrated to a depth of over a hundred feet through some of the small passageways. Then, losing his direction for some reason, instead of going on beneath the plateau he advanced toward the valley sink area and encountered the mass of disordered fragments. For a short distance he was able to find crevices through which he could crawl feet first, but his movements dislodged some of the loose blocks which fell upon him and pinned him there.

The valley sinks.—The extensive sinks and hollows may now be pointed out. To the south of Mammoth Cave ridge are Deer Park and Doyle Valley (Figure 24). The general aspect of Deer Park is shown in Figures 6 and 11. Doyle Valley is much larger. It ramifies in all directions into the surrounding plateaus, and on its floor there are numerous pits and sinks, several of them containing permanent ponds. To the south of Elko ridge is a magnificent series of hollows separated from each other by bits of plateau that have been almost entirely consumed through the development of the numerous sinks. Owens Hollow and Woolsie Hollow constitute the eastern end of this system. Just west of Cedar Hill School we may note several large sinks which presumably represent the position of earlier drainage lines now dismembered by the development of sinks along the course of the stream, somewhat like the condition represented in block B of Figure 20. Hunts Sink and Double Sinks on the northeast side of Mammoth Cave ridge are of similar type. The finest example in the entire area of a valley whose headward portion has been replaced by a sink is to be seen on the northwest slope of Chestnut Grove ridge, just a mile southwest of Great Onyx Cave.

Near Cedar Hill School, too, there are many hollows which open out toward the Pennyroyal Plain at the south. These undoubtedly occupy the position of drainage lines formerly flow-

ing southward. In several cases these valleys in advancing headward have encroached upon other streams which flow to the north. It is impossible to state in every case whether this diversion or capture preceded or followed the development of the sinks.

North of Mammoth Cave ridge is another splendid valley sink or hollow known as Houchins or Eden Valley. Like all of the others it contains great depressions which head back into the bordering plateaus. East of Chestnut Grove ridge there is a vast area of sinks and depressions with an occasional mesa-like remnant of the former plateau standing out conspicuously above the lower pitted country. Part of this is known as Johnson Valley. This region has passed beyond the mature stage, for over wide areas all evidence of the plateau which at one time occupied this region has disappeared. The term late maturity may be applied to the stage of development here represented. Figure 24 shows only the margin of this tract of country. On the Mammoth Cave topographic sheet, however, much more of it may be seen.

THE CAVES AND THEIR DEPOSITS.

The development of caves. Caves are by no means found only in limestone regions. Lava flows, for example, often have extensive underground openings resulting from the fact that the surface of the lava cooled and hardened and the part still fluid beneath ran out, leaving a tunnel covered by a roof. Waves frequently produce caves along the coast by their constant pounding and washing away the weaker rocks. Sandstones and other types of sedimentary formations often have vertical cracks or joints which gradually widen through weathering or by slight movement of rock masses and these spaces may then be entered. Bears often have their dens in just such places.

The most extensive caves occur in regions of thick and comparatively pure limestone formations. The solubility of the limestone is of course the prime reason for the presence of the caves. Dense and massive limestones tend to a maximum development of caves because such beds are practically impervious to water except along fissures and bedding planes, and by the concentration of solution in certain places much larger cavities result. Comparatively porous limestones, on the other hand, which offer free passage for the water in all directions do not usually develop caves, nor sink holes, except where the circulation of the water is concentrated locally.

The chief constituent of limestone is calcium carbonate which is only slightly soluble in pure water, that is, chemically pure H_2O. Approximately 75,000 parts of water are required to take into solution one part of calcium carbonate. Rain water, however, is not strictly pure but contains some carbon dioxide which it absorbed from the air. These carbonated waters act upon the limestone and produce calcium bicarbonate, thus:

$$\underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} = \underset{\text{calcium bicarbonate}}{Ca(HCO_3)_2}$$

The resulting bicarbonate is 30 times as soluble as the calcium carbonate, even in pure water. But if the water still con-

tains some carbon dioxide it is even more effective as a solvent. We see, therefore, that the presence of carbon dioxide in the water, absorbed either from the air or from the soil renders it highly capable of dissolving away the limestone. In fact, the amount of water which falls as rain upon one acre of land in the Mammoth Cave region in the course of a single year is capable of dissolving some 25 or more cubic feet of rock. Or expressed

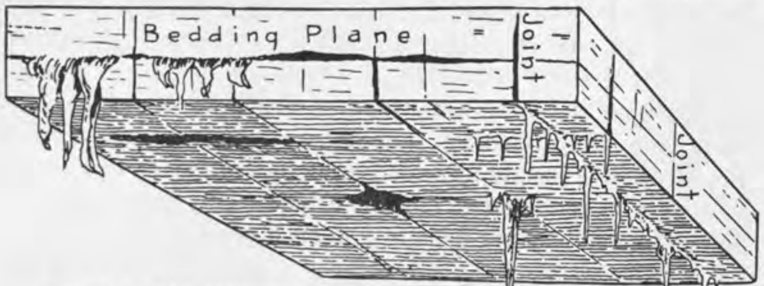

FIG. 26. DIAGRAM SHOWING BEDDING PLANES AND JOINTS

The bedding planes of the rocks in the Mammoth Cave region are practically horizontal, the joints are practically vertical. Both bedding planes and joints provide means by which water can work its way through the rock and hence bring about solution. Stalactites are here shown concentrated along the different planes.

differently, the rain falling on this region is easily capable of removing in solution one foot thickness of limestone from the entire region every 2000 years. Inasmuch as this solvent activity is concentrated so definitely in certain places it is not difficult to appreciate the method by which so many caves of such large size have been formed.

Concentration of water in massive limestones is effected in two ways, first along the joints or fissures, and second along the bedding planes. Nearly all stratified rocks are cut by cracks or joints, roughly vertical. These often occur in two sets or systems which intersect each other at nearly right angles (Figure 26). Such joints offer avenues whereby the water which has soaked into the soil may penetrate downward to greater depths. As the water descends along the joints, solution takes place, the joints are enlarged and crevices are formed. The intersection of two joints which cross each other is a particularly favorable spot for the penetration of water into the limestone. In such situations more or less circular openings are dissolved instead of the long narrow crevices produced along single joints.

Water which finds its way into the joints of the rock descends until its downward progress is brought to a stop. This may be the result of one of two causes: first, a bed, such as shale or a massive limestone layer which is impervious to water may be encountered; or second, the ground water table, or the depth at which all the openings in the rock are filled with water, may be reached. In either case, when the downward movement of the water is brought to a stop, lateral movement begins and channels are dissolved out along the bedding planes or in porous layers in the limestone.

Figure 27 depicts several stages in the development of caves and shows the relationship between the underground and surface features. In section A the drainage is practically all on surface features. In section A the drainage is practically all on the surface of the ground. Green River is shown in a valley but little below the surrounding country. The illustration simulates the Mammoth Cave region in showing a layer of sandstone capping the massive Mammoth Cave limestone formation. The sandstone does not readily permit surface drainage to seep through except at occasional places where joints occur. In section B we note that Green River has cut a deeper valley. This has lowered the ground water level and has enabled the water that seeps into the ground to penetrate deeper into the limestone mass. Several of the surface streams have been diverted to subterranean courses, and sink holes have thus begun to make their appearance. The position of sink holes has undoubtedly been determined by the presence of joints in the sandstone layer, whereby the surface water readily gained access to the limestone, or possibly by the fact that in places the sandstone was entirely removed by erosion.

Section C shows further advance. The river has cut to a lower level. The sink holes have been greatly enlarged. Surface streams have almost disappeared, except for the smaller rills, almost all of which find their way soon into the depressions. The cave system has now become more elaborate. Different "levels" may now be detected in the caves. These levels may be due to the presence of especially pervious or soluble beds in the limestone or to the fact that the river halted temporarily at different levels during the time that it was cutting down

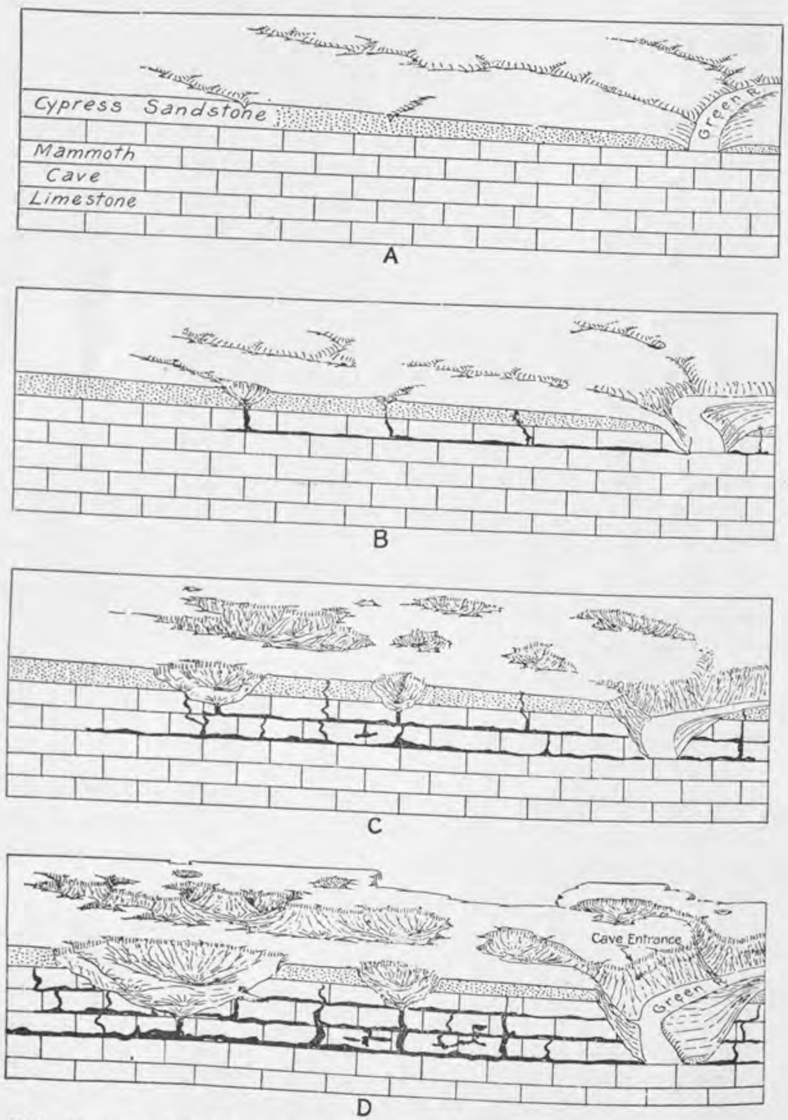

FIG. 27. FOUR STAGES IN THE DEVELOPMENT OF THE MAMMOTH CAVE REGION

These drawings show the conditions which result from the gradual cutting down of the Green River. A detailed discussion is given in the text.

its valley. It seems likely that the greatest activity in cave formation takes place along the joints down which the surface water is making its way into the caves, and in the bottom level where most of the surface water is concentrated. Some of the upper levels may of course at the same time still function as channels.

Section D shows by no means the final stage but only the conditions approximately as they exist in the Mammoth Cave region at the present time. Extensive valley sinks break the plateau up into different parts. The cave system is highly developed. The vertical channels have been greatly enlarged by running water so as to produce large underground cavities of great height. When viewed from the lower levels of the cave with which they communicate they are known as "domes," though rarely are they dome shaped. In fact they are usually narrower at the top and flare out at the bottom. The frontispiece gives the general aspect of such a dome. The walls, fluted and channeled by running water, rise majestically to great heights into a realm of darkness, like the walls and columns in the interior of a Gothic cathedral. From an upper level a view down into one of these great wells is equally impressive. The lower portion is called a pit.

In section D the sinks have increased in area through the weathering back of their walls. Sinks occasionally are enlarged by the collapse of the cavernous passageways beneath them. When this occurs they are apt to have steep sides. However, it is not believed that this occurs very commonly, nor is it believed, as is occasionally stated in text books, that natural bridges are generally formed by the collapse of the roof of a cave, one portion of which still remains intact. Not that this is impossible but that the general collapse of a cave almost never occurs. In fact no natural bridges are known in the Mammoth Cave area.

The sandstone capping at the top of the plateau (Figure 27, section D) causes the upper portion of the walls to have a vertical form but the lower slopes are more gentle. It is here that cave openings may occasionally be discovered. Were it not for the accumulation of talus and debris washed from above many more cave openings around the valley walls would be visible.

Cave channels and passageways are developed not only by the solvent action of water but also by its erosive force, in the same manner as on the surface of the ground. This is aided by the fact that the underground streams often contain a great deal of silt which has been carried into them from the surface of the region above. When it is realized that all the material which formerly filled the spaces now occupied by the sinks and depresssions has been carried underground through various swallow holes in the floors of the sinks it is easy to understand that much sand and silt must thus be carried into the caves. This sand and silt comes in part from the disintegration of the capping sandstone layer, and in part is the residual soil left after the limestone is dissolved away. This residual limestone soil is usually red or orange in color. Accumulations of it may be seen in practically all the caves of the region.

This silt is the source of the nitrate deposits for which Mammoth Cave was exploited during the War of 1812. Nitrates of calcium, sodium, and potassium are present in this earth and are probably derived from the excretions of bats which formerly lived here in great numbers. In some of the caves many bats are still found. In some of the halls of Colossal Cavern hundreds if not thousands of bats are to be seen hanging in groups of dozens from the rough ceiling. The nitrates were leached out from this "peter dirt" as it was called and the resulting saltpeter was used in the manufacture of gunpowder. During the Civil War many of the caves of Tennessee provided a similar source. Water was conducted into the cave through a wooden pipe and the concentrated solution pumped back to be evaporated outside of the cave. These pipe lines and leaching vats are still seen by all visitors to the cave.

Cave passageways in general are of two types, those which follow the joints and those which follow the bedding planes. The former are apt to be high and comparatively narrow. The latter are apt to be wide and comparatively low. However, both types, after they have been produced, are much modified by the constant cracking off of fragments from the walls and roof. This material, falling on the floor of the cave, is ground up and washed away by streams of water. Sometimes gigantic "halls" result, having a height of 100 feet or more, and encompassing

an area of an acre or so. When the ceiling of a cave consists of a firm and massive layer of limestone it is less subject to destruction in this manner. Some such ceilings extend over thousands of square feet of cave, as flat and uniform as an artificial structure.

The natural tendency, however, is to develop the form of an arch inasmuch as this provides the greatest strength. Sometimes the material which has broken from the ceiling accumulates in such quantities on the floor of the cave as to close it off entirely, though usually there are little openings between the top of the pile and the ceiling through which a person can crawl. Explorers in caves are rarely daunted in following a large passageway, to find it interrupted in this manner, knowing that beyond the obstruction it will open out again.

Cave Deposits. To most visitors the deposits of calcium carbonate in the form of stalactites, stalagmites, and other fantastic shapes constitute one of the chief features of interest in caves. The deposition of this material is due to the fact that water containing carbon dioxide seeping through the limestone takes into solution appreciable quantities of calcium carbonate. If the water moves through the rock quickly and finds its way promptly to an underground stream it will be able to carry off all that it has had opportunity to dissolve. But if it is delayed in its progress due to the fact that it goes through very small cracks, and also if it comes through in relatively small quantities so that its flow is not rapid, it has opportunity to become saturated with mineral matter in solution. Then as it drips slowly from the ceiling or flows in an extremely thin film over rock surfaces, it evaporates and the material in solution is deposited. Another reason for the deposition of mineral matter is the fact that it loses its carbon dioxide due to agitation as it trickles over rough rock surfaces. And as we have noted before, the presence of carbon dioxide makes the water many times as effective a solvent of limestone as if it were strictly pure water.

Stalactites. Figure 28 shows in the upper-most view several of the forms commonly assumed by deposits of calcium carbonate. On the ceiling of the cave are to be seen the stalactites, hanging like icicles, but having greater variety of form than icicles do. Beneath the stalactites, and rising from the floor of

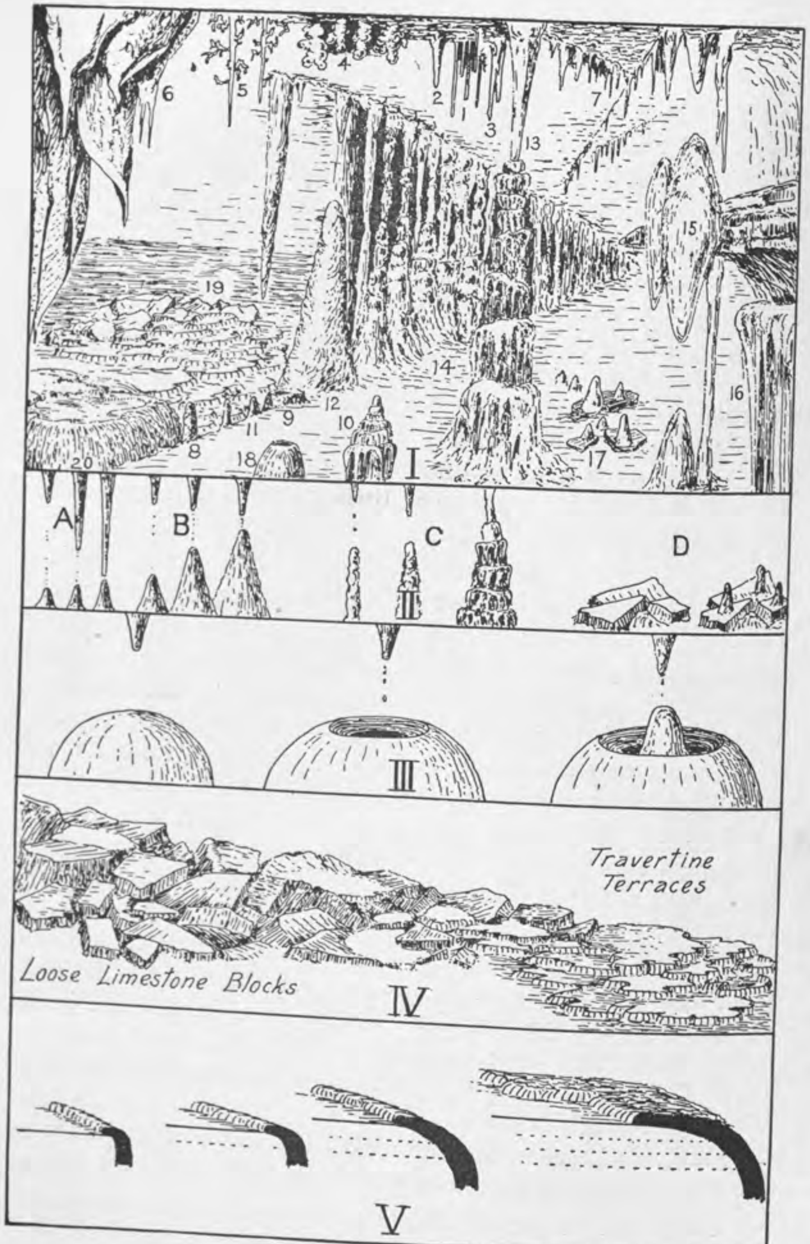

FIG. 28. CAVE DEPOSITS

I. Twenty kinds of cave formations are illustrated. II. A shows relation between stalactite and stalagmite when the dripping is slow. B shows relation when dripping is fast. C shows development of columns. D shows how stalagmites sometimes form on loose blocks. III. Stalagmite formed and then cut through at the top by a renewal of the dripping from above; this followed by development of new stalagmite in the center of the old one. IV. Development of terraces. V. Development of bowls or cauldrons, shown in No. 20 above. All of these forms are discussed in the text.

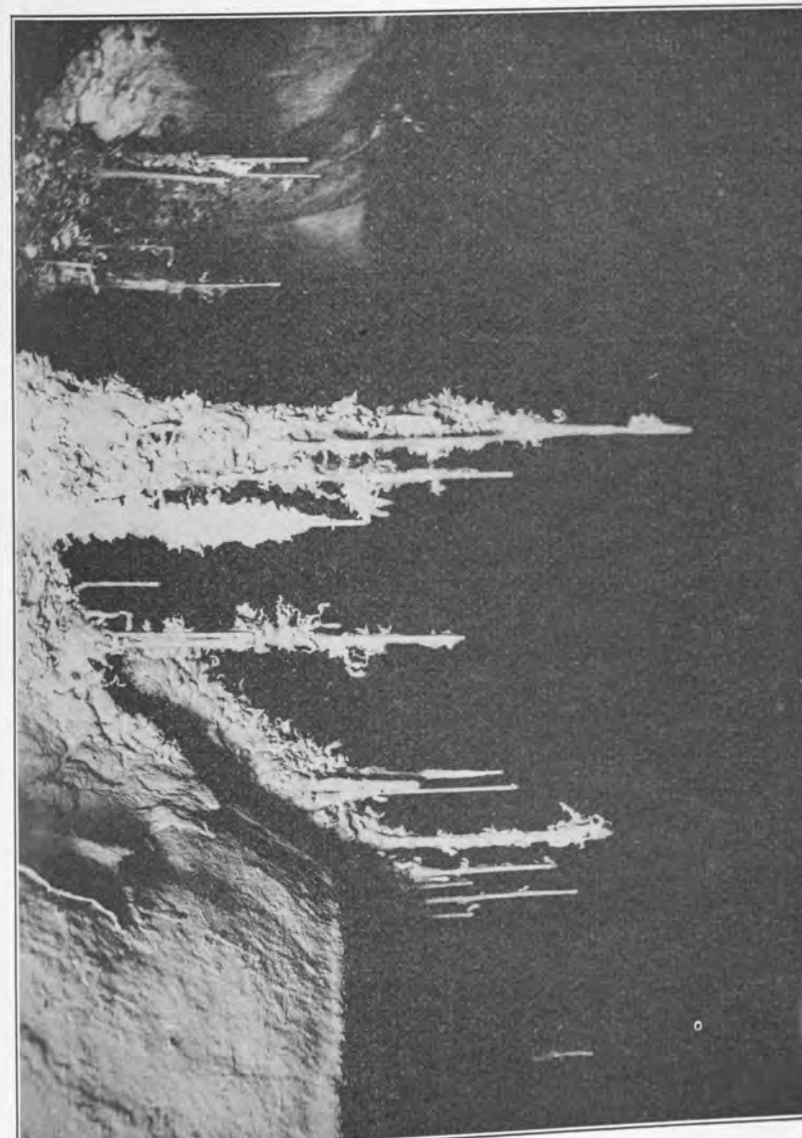

FIG. 29. STALACTITES COVERED WITH HELECTITES

These branching and twisted deposits result probably from impurities in the water which affect the direction of crystal growth. Most of the caves contain examples of this type. Those illustrated here are from the Great Onyx Cave.

the cavern, are the stalagmites, also very varied in their shape and size. Some of these different forms may now be considered, as to manner of origin. Form 1 is a long simple pendant. This results when the water seeping through the porous rock above flows relatively fast. Such forms are usually hollow. That is because a drop, first forming on the ceiling, evaporates most near its margin and this tends to build up a little rim which, as it increases in size, becomes a cylinder. The water flows through the tube thus formed and drops from its end. Such tubes are often extremely delicate, usually white or almost transparent, and quite uniform in thickness, having the diameter of a pencil for a length of a foot or more. In time, however, the opening in the center becomes so small by the deposition of mineral matter and perhaps also by becoming clogged with impurities, that the water starts to flow down the outside of the stalactite. This, as shown in No. 2, causes the stalactite to increase in thickness, especially at its upper end. Sometimes pronged forms appear, as at 3, where two stalactites become united. Grape-like clusters (4) result when the flow is less rapid, in fact when all the water evaporates without dripping off. Branching forms, known as helectites (5), (also Figure 29), result probably from the presence of impurities in the dripping water. These impurities, such as grains of sand or silt, accumulate on the outside of the stalactite and cause a change in the direction of crystal growth at those points. Sometimes great sheets or draperies are formed (6), (also Figure 30), frequently combined with other forms. These result probably from the fact that the water does not drip off from a single point but from a ledge. It also occurs when the water is highly charged with mineral matter and deposition takes place over a considerable area before the water has had time to concentrate in a single drop. Sometimes the draperies are colored with mineral matter, usually oxides of iron which give red, yellow, and orange tints to these translucent formations. Stalactites frequently follow the joint planes (7), (also Figure 31), in the ceiling because the water seeps most readily through those places.

Stalagmites. Stalagmites rise from the floor of the cave. They owe their position to the fact that water dripping from above lands on the floor and there evaporates, leaving its burden

of mineral matter. If the amount of water which drops down is relatively small so that it evaporates almost immediately the stalagmite is apt to rise rather pointedly from the floor. Its base will not be large (8). But if the amount of water which falls is considerable so that a little puddle is formed, then deposition will take place around the margin of the puddle and the resulting stalagmite will have a broad base (9) and usually a flat top or perhaps a slight depression at the summit. As the stalagmite grows up there may be a succession of flat disc-like parts and pointed columnar portions alternating with each other as shown at 10 in Figure 28. Around the margin of the discs are draperies and stalactites formed by water flowing down over the sides. Such forms are often extremely beautiful and frequently very elaborate in their make-up, especially if they are large.

The relation between stalactites and stalagmites may now be considered. If the stalactite drips very slowly so that most of the water is evaporated before it has a chance to fall off, then the stalactite will rapidly increase in length while the stalagmite rises very slowly, this being shown at 11 and at A in Figure 28. But, on the other hand, if the water remains suspended for only a short time, then the stalagmite instead of the stalactite shows the more rapid growth. This is shown at 12 and also at B in Figure 28. Other factors such as the concentration of the solution also play a part. When the stalactite and the stalagmite ultimately join a column is formed (13). Such columns, as might be imagined, assume every conceivable shape, dependent upon the various conditions above discussed.

Other interesting features shown in Part I of Figure 28 may also be pointed out. At 14 there is represented a row of pillars standing like a wall in the middle of the cave. These follow the course of a joint or crack. An example of this may be seen in Whites Cave near Mammoth Cave Hotel. A rather interesting combination of features is shown at 15 where a projecting ledge or shelf has intercepted the dripping from above and has caused the growth of a second set of stalagmites and stalactites. The flutings and columns shown at 16 are formed wherever water pours over a ledge or projection. Sometimes these reach magnificent proportions, as in the Corinthian Columns in Mammoth Dome of Mammoth Cave, or in the

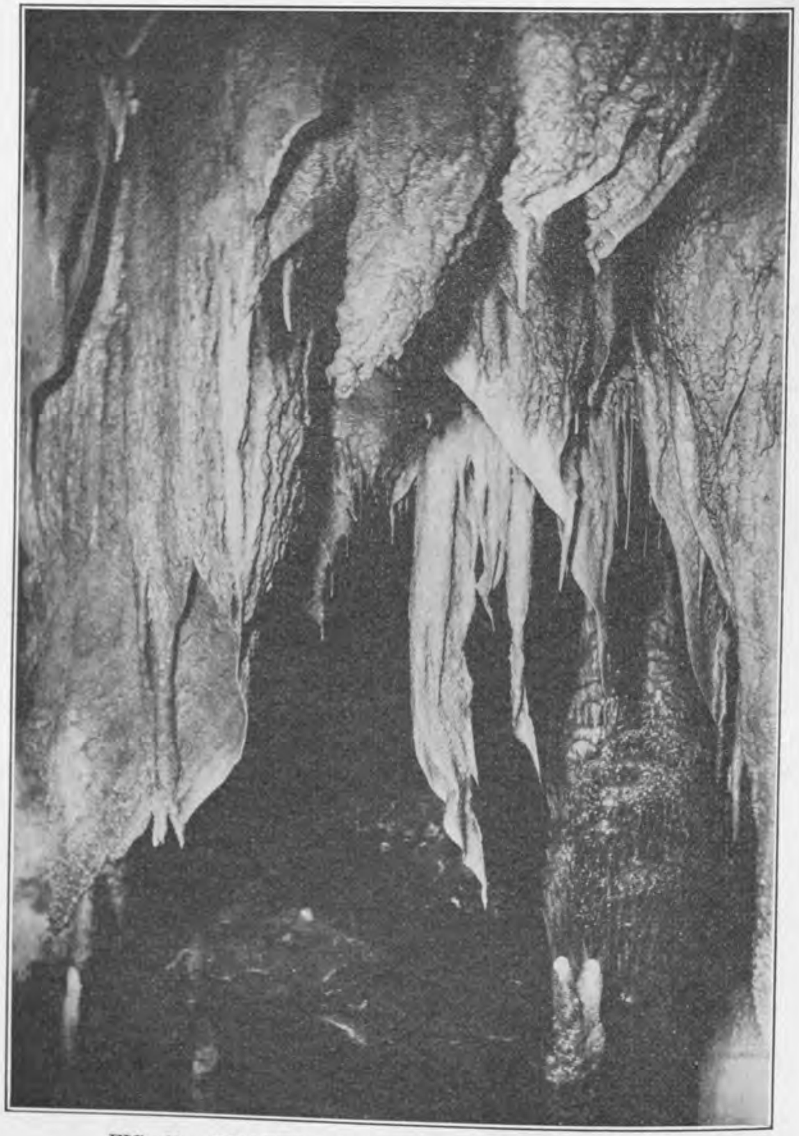

FIG. 30. DRAPERY DOME IN GREAT ONYX CAVE
Stalactites often assume the form of flat bands and sheets when the water flows over smooth surfaces and deposition takes place along an edge instead of at a single point.

Frozen Niagara of New Entrance Cave. This last mentioned feature is one of the most impressive sights in the whole Mammoth Cave region. At 17 and also at D just below, stalagmites are shown perched upon loose blocks which have fallen from the roof of the cave. Usually stalagmites are frozen so hard to the floor upon which they stand as to be quite immovable. Forms like those represented, however, can actually be carried around. In Violet City of Mammoth Cave there are several such blocks bearing stalagmites a foot or two in height.

The form shown at 18 in Figure 28, and also more clearly in Part III of the same illustration, is rather exceptional. It represents a stalagmite, more or less rounded at the top, as is frequently the case. After having assumed that form it apparently ceased growth for a time and became dry. This was followed by renewed dripping which, instead of adding to the deposit, actually wore through the top of the stalagmite, forming a kind of crater. This erosion was undoubtedly facilitated by the fact that when the stalagmite became dry it developed cracks and this made it a ready prey to the impact of water dropping from above. This may be followed, as shown in the same illustration, by the growth of another stalagmite in the center of the old one.

At 19 in Figure 28 we note the development of terraces. These resemble very closely the terraces of the Mammoth Hot Springs in Yellowstone Park. The mode of formation is suggested in Part IV of Figure 28. At first there is an irregular surface over which the water flows, accumulating here and there in pools. At the edges of the pools where it overflows calcium carbonate is deposited and this tends to build up a little rim. The water in consequence rises and the rim is further increased both in height and in length. Pool after pool develops in this fashion, at many different levels, until the whole irregular surface is covered over. At the far end of Whites Cave there is a fine display of this type.

Sometimes, as at 20, bowl-like or cauldron-shaped features are produced. The succession of events leading up to such a form is suggested in Part V of Figure 28. It is similar to the terraces in having a rim. This rim, however, not only grows in height but at the same time it advances inward over the surface of the water due to the deposition of material on its inner edge.

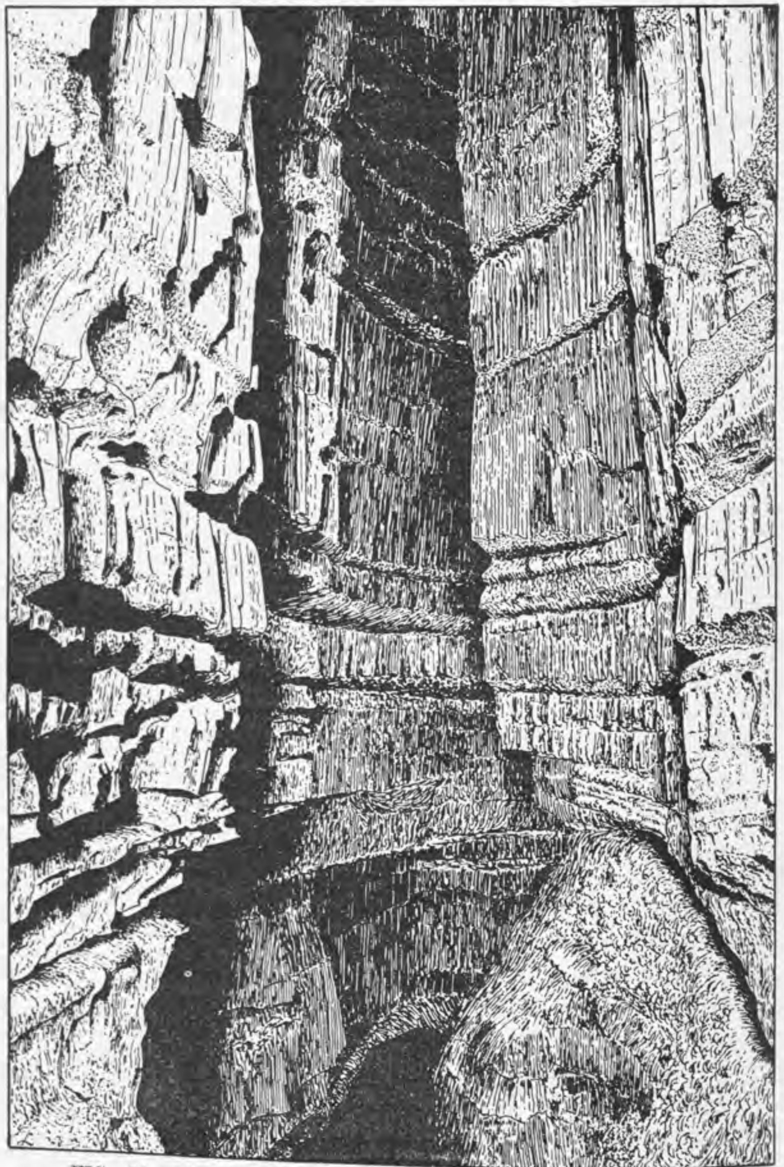

FIG. 31. VAUGHN'S DOME IN COLOSSAL CAVERN

The vertical lines are formed by running water which has come through from the surface of the ground above. The horizontal lines are due to the bedding planes of the limestone. The deep shadow, the absolute silence, and the magic beauty of the towering heights call to mind the interior of a Gothic cathedral. Domes of this type are found in several of the caves and are of special interest.

Sometimes the water level remains constant, in which case no increase in height takes place but the rim continues to encroach on the surface of the water, thus forming a flat shelf.

For most of the forms just described the term "onyx" is popularly used. Strictly speaking, however, onyx is a deposit of silica. Travertine is the correct name for these calcareous formations. The term "cave onyx" has also been suggested. Impurities of various kinds are always present. If in the form of iron oxide, the travertine assumes a reddish or yellowish hue, often very pleasing in tone. Sometimes manganese dioxide is present and this imparts a deep black color to the formations. The ceiling of many caves, as in Star Chamber, for example, of Mammoth Cave, is coated over with manganese dioxide which often takes the form of jet black patches. Crystals of calcite sparkling through the mass simulate the stars. The iron and the manganese in these instances have usually been leached from the formations overlying the limestone. Sometimes the iron oxide is deposited in cracks or joints of the limestone and there forms a very resistant vein which stands out like a ridge when the limestone is later dissolved away.

Crystal forms in caves.—Some caves exhibit beautiful sparkling surfaces coated entirely with calcite crystals. These deposits, unlike the travertine, were probably formed in the cave at a time when it was filled with water charged to a high degree with calcium carbonate in solution so that very slight changes in the conditions, as for example loss of carbon dioxide, caused some of the calcite to be deposited.

Gypsum or hydrated calcium sulphate is another common deposit on the walls of caves. The presence of sulphur is accounted for by the fact that pyrite is frequently found in the overlying shale through which the water seeps. Moreover, analyses of the limestone show considerable calcium sulphate to be present in the rock itself. Sometimes the gypsum deposits take the form of elaborate rosettes several inches in diameter, often of exquisite beauty (Figure 32). In other places the gypsum occurs as long hair-like fibrous crystals on the walls or in the silt filling the caves. Epsomite or magnesium sulphate occurs in some caves as masses of fine fibrous crystals coating

FIG. 32. GYPSUM CRYSTALS IN GREAT CRYSTAL CAVE.
The gypsum crystals assume the form of flowers or rosettes, curving out as long snowy white fibers from a central point.

the cave walls. It is found abundantly in Great Salts Cave and also in parts of Mammoth Cave.

Cave Life. The two commonest forms seen by all visitors to the caves are the small brown bats and the so-called cave cricket or Katydid, both illustrated in Figure 33. Some of the

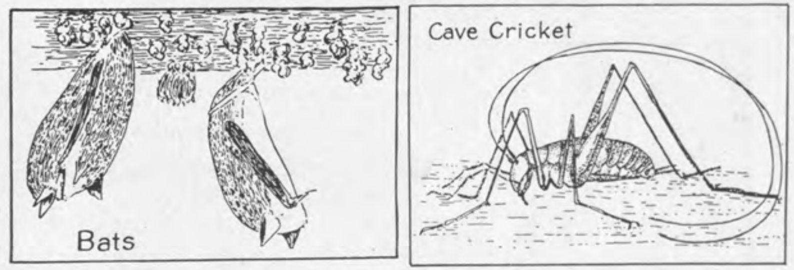

FIG. 33. EXAMPLES OF CAVE LIFE
The little brown bat is very abundant in some of the caves, notably in Colossal Cavern where thousands of them may be seen hanging in clusters from the ceiling. The cave cricket, really a katydid, is to be seen in every cave. Its very long antennae are extremely sensitive and compensate to some extent for its sightless eyes.

white or almost transparent blind crawfish are also to be seen in the pools. Numbers of small cave beetles abound in a few places. In the list of references citation is made to sources of information upon these interesting forms.

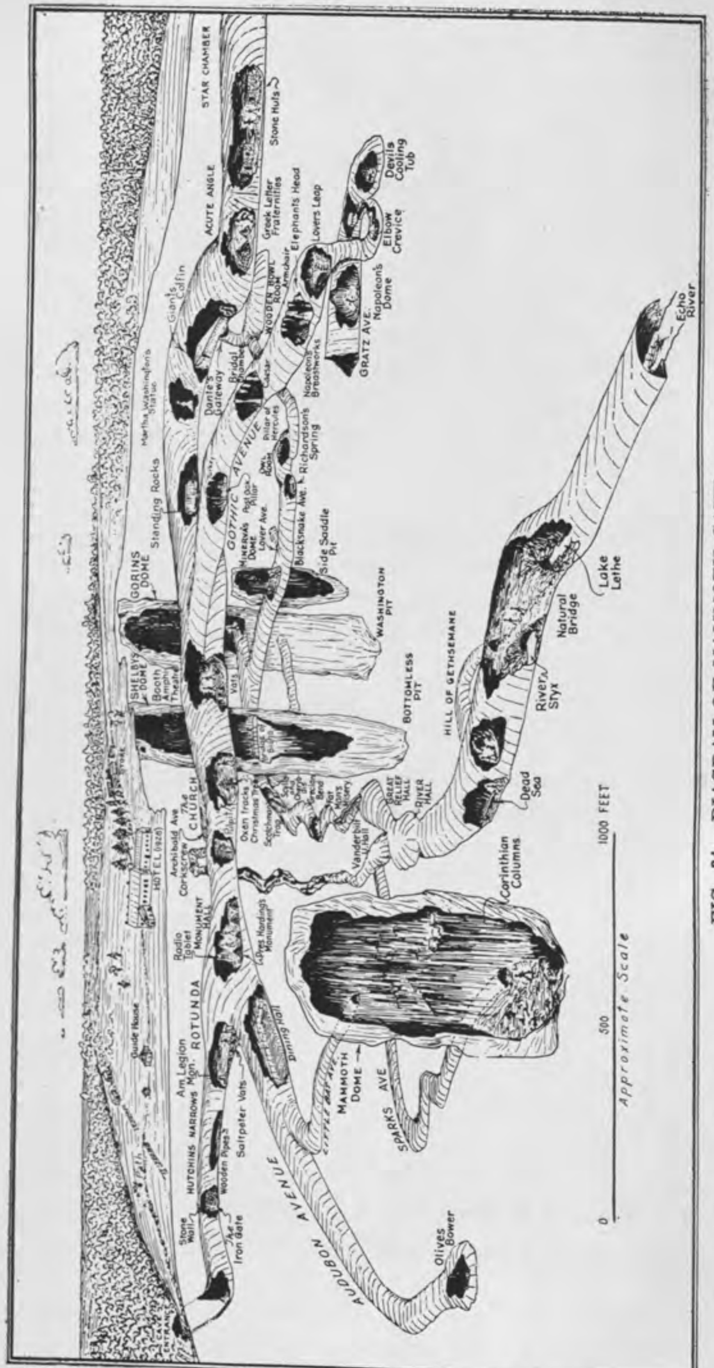

FIG. 34. DIAGRAM OF MAMMOTH CAVE
Showing graphically the passageways which are followed on Routes I and II. Described more fully in the text.

DESCRIPTION OF MAMMOTH CAVE

The average visitor, after a trip through Mammoth Cave, comes out above ground with little or no idea of the relative position of the various passageways he has traversed. The large diagram, Figure 34, of the cavern reproduced herewith attempts to portray in a graphic manner that portion of the cave which is most frequently visited. In fact, only those parts covered on the standard routes No. 1 and No. 2 are shown. Trip No. 3 takes us far beyond Star Chamber along the main avenue of the cave. Trip No. 4 goes down to Echo River and then four miles or so beyond, some of it by boat, and all of it along the lowest level of the cave. The various pasageways and domes illustrated in the diagram, intricate as they seem, represent only a portion of the many caverns and openings known to exist under that part of the plateau.

It is quite unnecessary to present here a detailed account of the features of interest to be seen on the trips through the cave inasmuch as several excellent guide books already render that service. The diagram can well be used in conjunction with any of the guide books. Most of the features mentioned therein are depicted on the drawing. A few facts of general interest may not be unwelcome, however.

The diagram shows more or less clearly a number of different cave levels. The main avenue of the cave, sometimes known as Broadway, represents the second level. The first level is a bit above it and is represented by Gothic Avenue, entered by a stairway from Booth Ampitheater. The third level lies beneath the second level. It is represented by Blacksnake Avenue which is entered by going through Dante's Gateway from the Main Avenue at Giant's Coffin. It is from this level that three domes are visited, namely Minerva's Dome, Gorin's Dome, and Shelby's Dome. Below each dome is a corresponding pit, known respectively as Side Saddle Pit, Washington Pit, and Bottomless Pit.

The fourth level is reached from the third level by going through the Scotchman's Trap and Fat Man's Misery to Great

Relief Hall. This hall, with Vanderbilt University Hall and Sparks Avenue, constitute parts of the fourth level. From this level Mammoth Dome is visited. Inasmuch as this level brings the visitor out near the bottom of the dome, the corresponding pit is not very deep and does not therefore receive any particular designation.

Mammoth Dome can also be visited through Little Bat Avenue from Audubon Avenue, representing part of the second level. This comes out near the top of the dome. It is not a part of any regular trip but it is used as a route through which lumber for bridges and boats can be taken to the river level without going through the various narrow and roundabout passages heretofore mentioned. The lumber is lowered from the mouth of Little Bat Avenue by a pulley to the bottom of Mammoth Dome whence it is but a short distance to River Hall.

The fifth level is that of Echo River and is reached by passing from the fourth level through River Hall. Practically all of Trip No. 4 follows this level, whereas all of Trip No. 3 follows the second level.

In addition to the levels mentioned there are many other intermediate levels. Moreover, any given "level" does not remain constanly level but may have a range in elevation as great as 40 feet. The various levels correspond with bedding planes of the limestone. Throughout the cave the horizontality of the rock is apparent. Sometimes, as in Gothic Avenue, beautiful flat ceilings may be noted, where the limestone is free from joints. It is on this ceiling that so many of the old names are to be seen, marked there with the smoke of candles as early as 1817. The departure from horizontality in the floor of many of the avenues, notably on the main avenue followed on Route No. 3 to Violet City, is due to the accumulation of tabular blocks that have fallen from the ceilings. Such fragments are apt to be abundant where the rock is most intersected with joints.

The domes and pits of the cave correspond with widened joint planes and have a vertical extent almost from the plateau surface to the river level. There is no doubt that these have been formed by water seeping through from above and finding an outlet below at the lowest level of the cave. In some places, as

at the Corinthian Columns in Mammoth Dome, part of the burden of limestone thus removed has been redeposited.

In addition to the avenues which correspond with the bedding planes and to the domes and pits which represent the vertical joints, there are occasional smaller and much more devious ways from one level to another, formed by currents of water. Such channels are often narrow and show clearly the scouring effect of the moving water. Elbow Crevice at the end of Gothic Avenue is the best example. Fat Man's Misery is somewhat similar. Still another type of passageway is that represented by the Corkscrew which provides a very direct means of getting from the main cave, second level, down to the river level. It owes its presence to the breaking away of a great mass of limestone. Numerous blocks of all shapes and sizes became dislodged and it is through this maze of disordered rock that the Corkscrew makes its way.

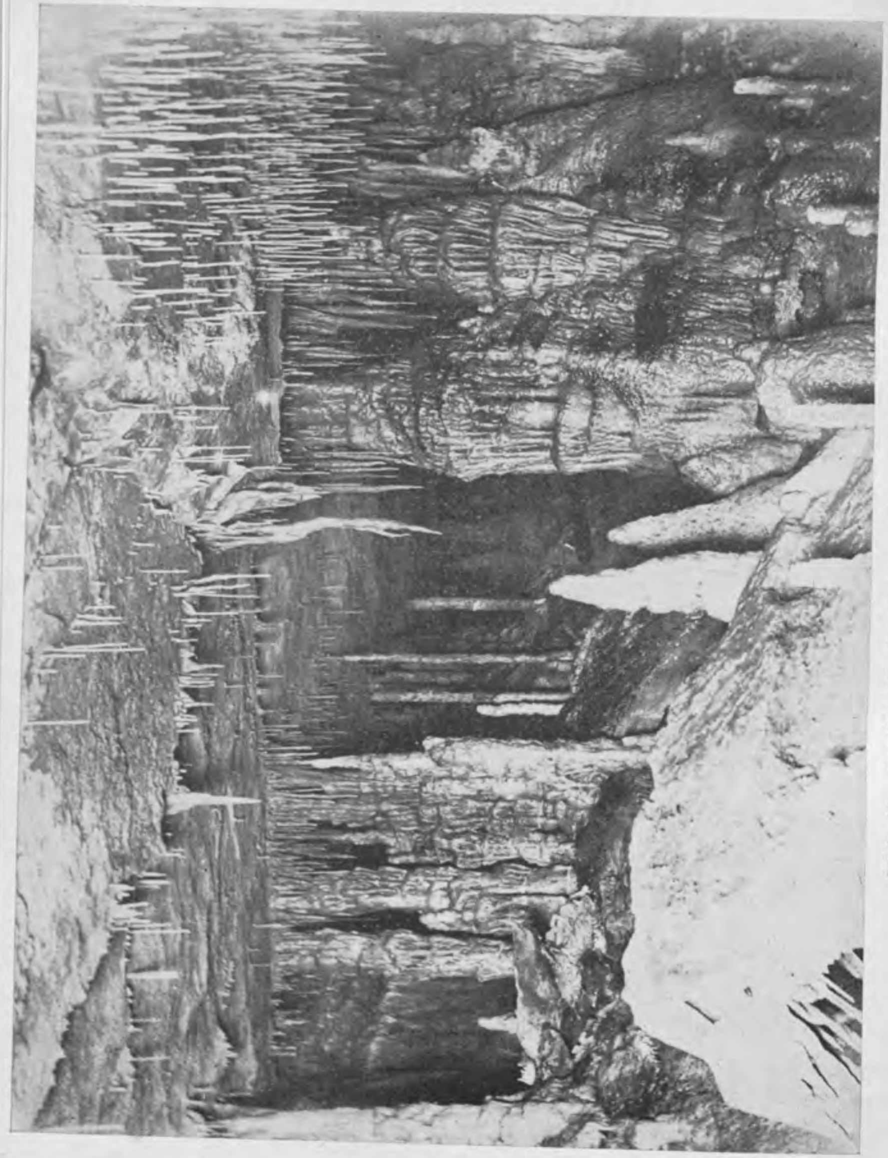

FIG. 35. TERRACE COLUMNS, GREAT ONYX CAVE

A typical cave interior showing stalactites, stalagmites, and columns of different shapes. The stalactites frequently follow the joints in the ceiling.

NOTES ON THE HUMAN GEOGRAPHY OF THE MAMMOTH CAVE NATIONAL PARK REGION

To the person interested in human geography the contrast between the sections north and south of Green River is of especial interest. In both sections, as in practically all other parts of the world, the local or smaller physical forms are influential primarily in the way they affect the location of cultural features such as roads and towns, and in the utilization of the land. Taken in a large way, the general tone or quality of the region is imparted by its accessibility to or remoteness from the driving forces of the world.

Thus viewed, we mark at the outset that the entire area is just off the great lane of travel which traverses the Pennyroyal Plateau from Louisville to Nashville. While relatively rugged the region offers no especial difficulty to penetration. The Dripping Springs Escarpment is by no means a barrier. And consequently we find the influence of the outside world reaching into this hilly belt with little interference for ten miles or more until the Green River gorge is encountered. This interposes a barrier to farther penetration and introduces an element of isolation to the region lying beyond. Moreover, the region lying between the Pennyroyal and Green River has its many caves to which annually thousands of tourists find their way. This helps to maintain a close contact with outside influences and to diversify the activities of the people who constantly live there.

As a whole, the region south of Green River is an agricultural one. The farms are located on top of the mesa-like plateau areas because there the land is level, and the soil derived from the capping sandstone is good and retains a large amount of moisture, whereas in the extensive sinks every drop of rain disappears immediately far underground. Occasionally the lower parts of the sinks are cultivated, but their inaccessibility, small extent, and inconvenient forms cause such patches to be of very little importance.

The character of the agriculture here is directly the result of the conditions mentioned. Tobacco constitutes an important

cash crop, readily sold on the Pennyroyal Plateau where the raising and marketing of tobacco is a staple industry. The production of garden vegetables and fruits, and the raising of chickens, all for the nearby hotels, is an important element in the agricultural life. But by no means do the people in this

FIG. 36. RAILROAD TIES READY FOR SHIPMENT BY BOAT ON GREEN RIVER

Practically every farmer derives some income from this source. The ties are of oak and sell for about thirty-five cents each. They are trimmed by hand with a large ax, the preparation of one tie taking about twelve to fifteen minutes.

region depend upon agriculture. There are numerous opportunities to work around the hotels and caves, to build roads, and to serve tourists in other ways, to say nothing of the ease of getting work in the nearby towns of the Pennyroyal. This accounts for the negroes found living in this region. With opportunities such as these they are able to survive with little need for initiative on their own part.

Besides farming there is also the cutting of timber and the making of railroad ties (Figure 35). Although this industry is no longer the great predominating activity it once was when thousands and thousands of ties might be seen on the river awaiting shipment by barge down stream to Evansville on the

Ohio, nevertheless it still constitutes a welcome source of income to practically every farmer.

Throughout this region one of the foremost problems is that of water supply for both animals and man. Figure 36 illustrates diagrammatically several of the devices used. At the right is

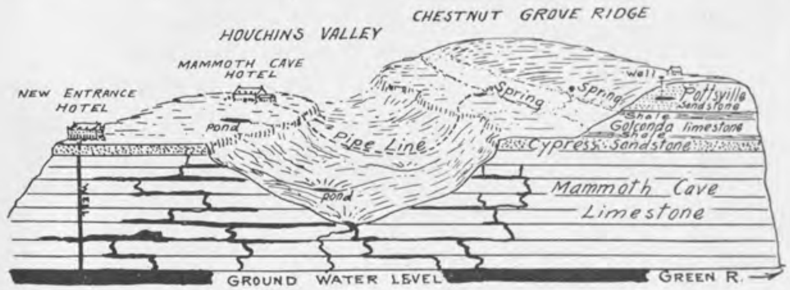

FIG. 37. DIAGRAM SHOWING VARIOUS SOURCES OF WATER SUPPLY

These include shallow wells in the Pottsville formation, deep wells reaching to the Green River ground water level, springs at various levels, and ponds in the sink holes.

Chestnut Grove ridge, capped with Pottsville sandstone. The farmers in this region put down shallow wells about fifteen feet deep until they strike small amounts of water held up by slightly impervious beds. These are known as perched water tables. Below the Pottsville are two pronounced shaly layers separated by the Golconda limestone. Each of these shaly beds is impervious and causes the water to seep along the bedding plane and appear on the hillsides in the form of springs. Several farms are thus supplied, especially those on the lower slopes. The water from such a spring is carried by pipe line to Mammoth Cave Hotel two miles away. The New Entrance Hotel, not having access to such a source, was obliged to drill a well several hundred feet deep until it reached ground water level below the plateau. For animals the ponds which occasionally are found in the bottom of sink holes constitute a very important source of water in the valley sink area.

The region lying north of Green River, and constituting about one-half of the proposed National Park, is not likely to be frequented very much by tourists. For many years its detached position forced the inhabitants to be dependent largely upon their own resources and ingenuity. Many of those who now

live there made their own clothes from the wool of their native sheep, and built their houses entirely from materials obtained right at hand. Indeed, some of these practices have not entirely disappeared. But gradually opportunities have provided contact with the outside world and now we find many of these people leaving their homes and securing employment in such places as the natural asphalt mines on the Nolin River near Brownsville. Farming, however, remains their chief occupation. Corn is a staple crop. Small mills run by gasoline power throughout the region provide corn meal for local use. Illicit stills are by no means unknown in this area.

NOTES ON READING MATERIAL

The most technical but at the same time readable description of the geology of this area is by Dr. James Marvin Weller in "The Geology of Edmonson County," published by the Kentucky Geological Survey in 1927. This presents in detail the chief facts relating to the geological formations and their characteristics and gives an account of the geological resources of the region from the economic standpoint, chief of which is rock asphalt. There is also a useful bibliography.

For Mammoth Cave in particular several interesting guides have been published, notably that by Horace Carter Hovey called "Mammoth Cave of Kentucky" and published in Louisville in 1912. This book gives an account of the things seen on the different trips through the cave as well as a description of Colossal Cavern. It includes, too, a chapter on the animal and plant life of the caves, and is well illustrated. Hovey's "Handbook of Mammoth Cave," published in 1909 is less elaborate.

Another similar guide by Helen F. Randolph is called "Mammoth Cave and the Cave Region of Kentucky." It was published 1924, at Louisville, and describes Great Onyx Cave, Crystal Cave, and several others. It includes an excellent bibliography of 96 titles on Mammoth Cave, prepared by Dr. Willard Rouse Jillson, State Geologist of Kentucky. Dr. Jillson has prepared another booklet called "Kentucky State Parks," published in 1924 by the Kentucky Geological Survey. This contains a brief description of Mammoth Cave as well as of a dozen other attractive regions of the state.

A description of the birds and mammals and other wild life of the region, including that found in the caves, is given by W. D. Funkhouser in "Wild Life in Kentucky," an illustrated report published in 1925 by the Kentucky Geological Survey.

Several articles relating to the physiographic development of features in limestone regions are worth attention by those interested in the scientific aspects of the subject. In 1910 J. W. Beede published a paper entitled "The Cycle of Subterranean Drainage as Illustrated in the Bloomington, Indiana,

Quadrangle,'' in the Proceedings of the Indiana Academy of Sciences. The principles evolved there apply equally to the Mammoth Cave area. A similar and more recent discussion by E. M. Sanders, entitled ''The Cycle of Erosion in a Karst Region,'' appeared 1921 in Vol. 11, page 593 of the Geographical Review. This is a summation of a larger work in French by Jovan Cvijic, a Serbian well known for his investigations on the karst topography of the Adriatic area. This paper is illustrated with several very excellent diagrams. Other references to German and French literature are included. In the Geographical Review for 1924, Vol. 14, page 26, Cvijic contributed an article on ''The Evolution of Lapies,'' the furrows so characteristic of some limestone regions, especially those having semi-arid conditions. Such features, however, are almost undeveloped in the Kentucky area.

A rather monumental work on caves in general is in French by E. A. Martel entitled ''Noveau traite des eaux souterraines,'' published in Paris in 1921, and reviewed in the Geographical Review, Vol. 11, page 630. In August, 1924, Dr. W. R. Jillson published in Vol. XLII of the Pan-American Geologist a very carefully prepared article entitled, ''American Karst Country'' which describes the unique sinkhole topography of this region in much detail.

An interesting account of the ''Evolution of the Map of Mammoth Cave'' up to 1896 is given by R. Ellsworth Call in the Proceedings of the Indiana Academy of Science for that year.

Attention should also be called to the splendid topographic sheets of the U. S. Geological Survey and Kentucky Geological Survey covering this area. The Mammoth Cave sheet is the most important. It shows all of the region lying between Glasgow Junction and Green River. North of this is the Cub Run sheet covering the northernmost part of the Park area. To the west of these sheets respectively are the Brownsville and the Leitchfield quadrangles. They include, however, hardly any of the Park area. These maps may be purchased from the U. S. Geological Survey, Washington, D. C., at 10 cents each, and are indispensable to anyone who wishes to have at hand an accurate representation of the topography.

Visitors interested in the human occupancy of this region will find two other reports of the Kentucky Geological Survey of the greatest interest. One by Carl Ortwin Sauer on the ''Geography of the Pennyroyal Plateau'' was published in 1927; the other by Wilbur Greeley Burroughs on the ''Geography of the Western Coal Field'' appeared in 1924. Both of these contain numerous maps, graphs, and illustrations, and explain the relation of the people and their culture to the landscape in which they live. A special report in this noteworthy geographical series is now being prepared for the Kentucky Geological Survey on ''The Barrens'' by Samuel N. Dicken. This will be published during the coming year and will add much to the literature of a detailed and specific character.

FIG. 38. AN OLD CEMETERY IN ONE OF THE VALLEY SINKS

On one of these stones is inscribed: "In memory of FRANCES JANE CHATFIELD, Born in Oneida, N. York, Sept. 20th, 1823, Died Nov. 22nd, 1849, aged 26 years 2 months and 2 days."

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